Vol. 1. No. 3. September, 1944.

THE QUEENSLAND JOURNAL OF AGRICULTURAL SCIENCE

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PUBLISHED QUARTERLY

By the Queensland Department of Agriculture and Stock, Brisbane

Issued by Direction of Hon. T. L. WILLIAMS, Secretary for Agriculture and Stock.

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THE QUEENSLAND JOURNAL OF AGRICULTURAL SCIENCE

VOL. 1. NO. 3.
SEPTEMBER, 1944

AN INVESTIGATION OF THE RAT PEST PROBLEM IN QUEENSLAND CANEFIELDS: 3. LABORATORY EXPERIMENTS ON FOOD INTAKE AND TOXICITY.

By W. A. McDOUGALL, M.Sc., Entomologist, Bureau of Sugar Experiment Stations.

SUMMARY.

1. Methods for the initial cage test evaluation of bait bases, poisons, poisoned foods and baits for Queensland canefield rats are described. Mean standard intake and median lethal dose, either singly or conjointly, are used as criteria.

2. Whole grain, such as that of wheat and oats, is the most efficient food bait base.

3. Thallous sulphate and yellow phosphorus are considered to be suitable poisons. Arsenic, barium carbonate, barium chloride, red squill, and strychnine are unsatisfactory for various reasons.

4. The addition of flavourings and/or attractants does not increase the intake of a particular poisoned food by individual rats: this can be varied only by altering the poison strength.

INTRODUCTION.

The primary object of the experiments concerned with food intake and with toxicity of rat poisons was to collect data on recognized rat poisons for use in field studies on poisoning. In initiating the experiments it was considered that cage test results would assist in the interpretation of field data and in setting out field experiments. It was appreciated, however, that field results cannot be expected to parallel those obtained in cage tests, since the factors which can be studied in part away from the field—viz., palatability, as expressed by intake, and toxicity—are only two of the many concerned in the successful poisoning of rats in the field.

No serious attempt was made during the course of the experiments to discover new rat poisons.

METHODS.

Except where it is stated to be otherwise, *Rattus conatus* Thomas was the test animal employed. In comparative studies only healthy, apparently normal, active adults were used. It is common experience that immature rats exhibit irregular and abnormal intakes expressed as a function of individual body weight. Old animals were excluded from the tests as their death from natural causes could be regarded as imminent. Occasionally these rats died in test cages without eating or after feeds of various amounts of unpoisoned food; many deaths were recorded after intakes of small, sub-lethal doses of poison, while other rats required the normal amounts of poison to kill them. A few rats of suitable age and size, when first placed in test cages, ate either no food at all or obviously sub-normal amounts. Such specimens were not as active as usual at the time, and most of them, whether transferred from dormitory living cages or from the field, behaved normally a few days later.

With cage experiments an effort is usually made to standardize the condition of test animals, and this often consists of holding wild captures in living cages for some period prior to testing and/or starving all specimens before offering weighed food or baits. None of these procedures was necessary in the case of the species used in this investigation: the use of suitable rats either direct from the field or from dormitory living cages was found to be

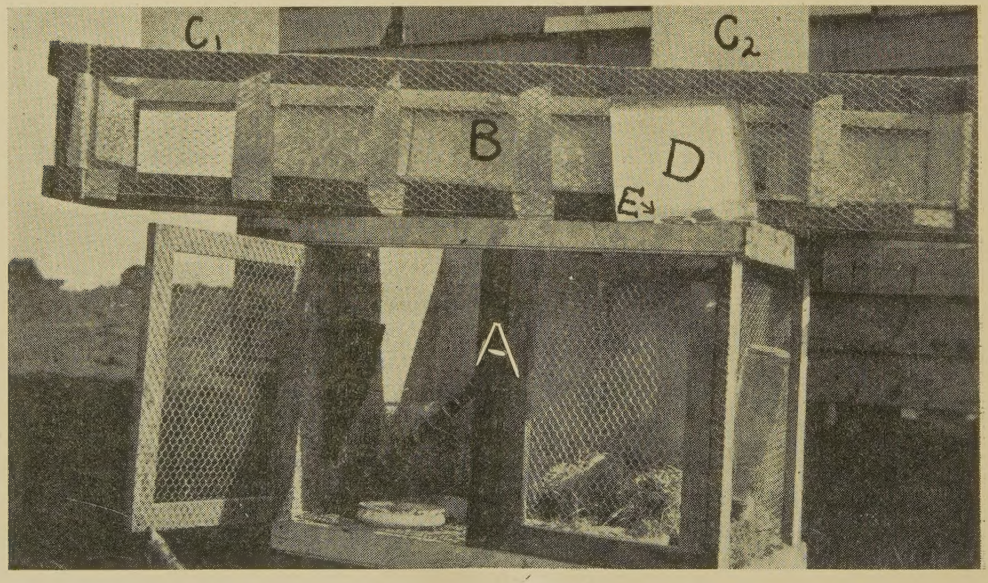

Plate 1.

RAT CAGES USED IN THE EXPERIMENTS:

A.—Breeding and living cages.
B.—Battery of six test cages.
C_1. and C_2.—Sliding backs of test cages.
D.—Tray floor of a test cage.
E.—Glass containers for poison work.

statistically sound, provided some simple precautions were taken. Those from fields for use on any particular day must be removed from traps before sunrise, and must be provided with bedding during travelling and while in the dormitory awaiting transfer to test cages.

Practically all of the cage work was carried out between July, 1937, and November, 1940, and about 3,500 rats were handled, mostly during the winter and spring months when field capture of suitable rats was easier than at other times. There is, however, no significant difference in food intake attributable to season of testing.

Test cages (Plate 1, B), each 10 inches x 11 inches x 10 inches, with removable tray floor (D) and sliding back (C_1, C_2), were arranged in batteries of six (B) and were always set up during the afternoon. Usually only one test rat was placed in each cage. All test animals and most test materials, the latter contained in glass containers (E) where necessary, were weighed before being placed in cages. For repeat tests the weight of a rat at the original test was usually taken; however, if a rat had increased in weight between tests the larger weight was used. On clearing cages during the morning—the test period was over one night—all animals, whether dead, sick or apparently normal, and all uneaten test material, were weighed. Live animals were transferred to dormitory living cages (Figure 1, A) for observation. To obviate fighting, which would interfere with the test results, care was taken to return dormitory rats to their original cages and field rats to unoccupied cages.

Takano and Konoda (1937), in reporting feeding studies with *Bandicota nemorivaga* Hodgson, a rat pest of cane in Formosa, listed food intake variations due to the presence of water, and many other investigators provide water in the test cages. With Queensland canefield species, under normal conditions, the presence of water has no influence on cage food intake. For overnight holding in the small test cages used it was unnecessary to provide bedding.

The common base for the poisons tested was a prepared food, made to the formula of the standard dormitory food*, but omitting the mixture of salts and Vita B, and passed through a $\frac{1}{2}$ mm. sieve. The poisons, after grinding when necessary, were thoroughly mixed with this fine material in the desired proportions by weight. Various grains and other potential bait bases were also used. The weight of any food material offered to a rat was always in excess of its stomach capacity, *i.e.*, intake would not be limited by the supply available. Feeding levels, or weighed amounts of food below normal intake and containing stipulated poison doses, were used sparingly and only when required for checking median lethal doses. Tests with unpoisoned food, primarily for periodical checking purposes, were also used in calculating food intakes. Attempts to use poisons in liquid form or in water solution were failures. This

* The formula of the standard dormitory food will be given in a later part of this series.

method is apparently inaccurate, unreliable, and also of little practical application in canefields.

The median lethal dose (M.L.D.), *i.e.*, the dose of poison which could be expected to kill 50 per cent. of the test animals, has been taken as the criterion for comparing toxicities. Food and bait base standard intakes are expressed as grams of food or bait base per gram body weight of rat (g./g.) and poison standard intakes as milligrams of poison per kilogram body weight of rat (mg./kg.). Weights of poisons when in salt form have been taken in all instances as those of the salts used and not as the calculated weight of any elements which may be the toxic principles.

Results of food preference tests, *i.e.*, tests in which two or more foods are offered simultaneously to a rat, have been examined by Analysis of Variance when three or more foods were concerned, and by the "Student" test for the difference between pairs when two foods were offered. Individual rats have been considered as blocks and each food as a treatment; the 5 per cent. level is taken for significance. The probable economic and practical value of preference tests for canefield work is doubtful; therefore, the recording of the results of such tests is merely formal. More emphasis has been placed on the mean standard intakes of foods presented singly to rats. Any series of such experiments examined statistically has consisted of not less than 25 tests, and a standard error is given.

It is necessary to distinguish between the terms *take, consumption, acceptance,* and *intake.* In the field, or in other control application work, poison baits when placed out may be counted. Later a check count is made and the difference between the original and check counts is called *take*; the *take* depends on the attractiveness and palatability of the bait, and the number and weights of rats or other animals interfering with them. Sometimes in the field when packeted baits are used those opened and eaten or partially eaten are examined. The estimate of the number of baits eaten is called *consumption. Take,* therefore, includes those baits accounted for by the consumption and missing baits. *Acceptance* is used in an indefinite manner in referring to palatability. On occasions, in reporting cage test results, all four terms are used in the literature indiscriminately. The author uses the term *take* only when material offered to animals has not been weighed or measured. *Intake* is the known weight of food or other substance ingested by a rat or rats.

Two classes of baits are recognised—viz., food baits and snap baits. In preparing food baits, attractiveness, intake, and toxicity are factors to consider so far as killing power is concerned. The poisoned food of food baits may be presented to rats by methods other than in baits. Snap baits should have some degree of attractiveness and very high toxicity, for under even the most favourable circumstances intake of a snap bait by an individual rat will be very small or negligible; its killing power depends on high toxicity and not on appreciable intake.

FOOD AND OTHER BAIT BASE INTAKES.

Choice of Base.

The choice of a food or other bait base for use in a rodent control problem is governed by palatability, availability, convenience of storage, ease of handling, deterioration qualities, suitability for use with particular poisons, and the scope of the problem, which includes areas and/or bulks infested and periods of infestation. These factors involve a consideration of the habits of the rodent species concerned, of the economic status of the problem, of the working environment, of the manner of presenting poisoned foods to the pests, and of the methods of preparing the poisoned foods, *i.e.*, whether in bulk by manufacturers or in small lots, as required, by individual farmers or other people concerned. Food and other bait bases listed by numerous authors therefore cover a wide field, although most food baits for use on a large scale against vegetarian species have either grain or grain derivatives as bases.

In Table 1 are given the more important foods used in the author's experiments and the respective mean standard intakes by *R. conatus*. The mean standard intake of wheat by *Melomys littoralis* is 0·133± ·003 g./g.

Table 1.

SHOWING MEAN STANDARD INTAKES OF FAVOURED (A) AND SECONDARY (B) FOODS.

	Food.		Mean Standard Intake g./g.
A	Prepared food		·071 ± ·004
	Rolled oats*		·074 ± ·003
	Hulled oats*		·066 ± ·006
	Unhulled oats*		·064 ± ·007
	Hulled barley		·071 ± ·004
	Wheat		·064 ± ·002
	Whole maize		·055 ± ·003
	Cracked maize		·057 ± ·004
B	Bread	1st night	·048 ± ·012†
		2nd night	·040 ± ·008†
		3rd night	·025 ± ·001†
	Bran		·032 ± ·004
	Peanut meal		·010 ± ·006
	Sugar cane		·465 ± ·063‡

* From a reading of Doty (1938) the following synonyms are apparent :—

Australia.	*Hawaii.*
Cracked or hulled oats	Rolled oats
Rolled oats	Crushed oats.

† Correction, based on weighed checks, has been made for drying out.

‡ Correction, based on weighed checks, has been made for drying out of cane and frass. Weight of frass has been allowed for.

Intakes of meat, fish, cheese, bacon and other animal products by murine species indigenous to Queensland canefields are so poor that a detailed consideration of these materials is unnecessary.

Dry foods in Table 1 are divided into favoured or desired foods (A) and secondary foods (B). Intakes of dry intimate mixtures of favoured and secondary foods depend on the mean standard intakes of the individual foods and the relative percentages of the two food types. Poor intakes are recorded when the percentage of secondary foods is high. Separate discussions of the two types of food are given hereunder.

Favoured Foods.

Contamination.—It is common experience that rats will not eat food affected by moulds, weevils, or ants.

Rat Preference for Different Grains.—Two-food and three-food preference tests with four grains showed the order of preference to be oats, maize, wheat, barley. An example of a two-food preference test is given in Table 2.

Table 2.

SHOWING RESULTS OF A PREFERENCE TEST WITH HULLED OATS AND WHOLE WHEAT.

Rat No.	Foods.	Individual Food Intakes. g.	Total Intake. g.	Standard Intakes of Individual Foods. g./g.	Standard Intake. g./g.	Weight of Rat (g.), and Sex.
1541	Hulled oats ..	7·63	7·77	·065	·066	117 ; F.
	Whole wheat ..	0·14		·001		
1542	Hulled oats ..	12·24	14·24	·051	·059	242 ; M.
	Whole wheat ..	2·00		·008		
1543	Hulled oats ..	9·51	9·51	·075	·075	127 ; F.
	Whole wheat ..	0·00		·000		
1544	Hulled oats ..	6·55	7·66	·056	·065	118 ; M.
	Whole wheat ..	1·11		·009		
1545	Hulled oats ..	7·19	9·64	·047	·063	153 ; M.
	Whole wheat ..	2·45		·016		
1546	Hulled oats ..	8·40	9·94	·060	·071	140 ; M.
	Whole wheat ..	1·54		·011		
1547	Hulled oats ..	5·39	5·39	·055	·055	98 ; M.
	Whole wheat ..	0·00		·000		
1548	Hulled oats ..	3·51	5·40	·039	·060	90 ; F.
	Whole wheat ..	1·89		·021		
1549	Hulled oats ..	5·36	6·63	·063	·078	85 ; F.
	Whole wheat ..	1·27		·015		

Mean Hulled Oats	Mean Whole Wheat	Mean difference, Hulled Oats—Whole Wheat	Result
0·057	0·009	0·048 ± ·006	Highly significant

Percentage preference	
Hulled Oats	Whole Wheat
86%	14%

Mechanical Condition of Grain.—*Rattus conatus* prefers the cracked grain of a particular cereal and *Melomys* spp. the whole grain. Some results of two-food preference tests with *R. conatus* are as follows:—

Rolled oats v. oats: Significant preference for rolled oats.

Rolled oats v. maize: Significant preference for rolled oats.

Unhulled oats v. cracked maize: Significant preference for unhulled oats.

Unhulled oats v. wheatmeal: Significant preference for unhulled oats.

Hulled oats v. flour: Significant preference for hulled oats.

Cracked maize v. flour: Significant preference for cracked maize.

Cracked maize v. wheatmeal: Significant preference for cracked maize.

Cracked maize v. wheat: Significant preference for cracked maize.

Wheat v. cracked wheat or wheatmeal: Significant preference for cracked wheat or wheatmeal.

Wheat v. cracked barley: Significant preference for wheat.

Wheatmeal v. cracked barley: Significant preference for wheatmeal.

Judged on intake, it is concluded that the grain substance is of more importance than the mechanical condition of the grain.

Wetting of Grain and the Addition of Solutions.—The introduction of poison into grain for use in the field is usually effected by the addition of the poison in water solution or in a fluid mixture. The wetting of whole grain has a tendency to reduce intake, while the grain is wet, but on drying the intake is usually normal provided the grain has not become mouldy. This is not so with cracked grain or grain derivatives. As an example: Rolled oats, wheatmeal, and prepared food were wetted by water or by a solution, without the poisons, such as used by Barnum (1930) for the preparation of strychnine-wheat and thallous sulphate-wheat. These foods were then dried and test fed to rats. The intakes under optimum conditions were only approximately 50 per cent. of those of the unwetted foods. In fact, favoured foods such as cracked grain or grain derivatives when wetted and dried are reduced to the status of secondary foods. This has an important field application, for the wetting or dampening of grain or grain derivatives is unavoidable under most field conditions.

Starch paste (which is sometimes used for the introduction into whole grain food of insoluble poisons), molasses, and golden syrup have little effect on intake of grain food, provided they are used in comparatively small amounts.

Addition of Flavourings and Attractants to Favoured Foods.—The records of a typical series of three-food preference tests, with raw linseed oil added in turn to one of the foods immediately before testing, are given in Table 3. The results indicate that fresh raw linseed oil is an attractant. Single-food feeding tests demonstrate, however, that its use does not increase the mean standard intake of any food by an individual rat; this intake depends

on the food substance itself. In other words, linseed oil, and similarly other known attractants, are purely attractants and not appetizers or flavourings. Materials used as attractants are usually poor foods and are added to grain bait only as thin smearings. Furthermore, if a series of tests as recorded in Table 3 is repeated three or more days after the attractant has been added to the food its presence is not indicated by intakes; the effect of all known attractants is transient. This point is also demonstrated when trapping. A well-used trap may be liberally coated with dry linseed oil, but for rebaiting a few drops of fresh oil must be added to the bait base carrier (McDougall, 1944).

Table 3.

SHOWING EFFECT OF RAW LINSEED OIL ON FOOD INTAKE.

Test.	Food Offered and Percentage Preference.	Summary of Results.
A (9 rats)	Barley .. 11·2 Oats .. .. 63·9 Wheat .. 24·9	Intake of oats significantly exceeds those of barley and wheat.
B (7 rats)	Barley .. 7·3 Oats .. .. 58·8 Wheat plus linseed oil .. 33·9	Intake of oats significantly exceeds those of barley and wheat plus linseed oil; wheat plus linseed oil exceeds barley.
C (8 rats)	Barley .. 0·7 Oats plus linseed oil .. 97·0 Wheat .. 2·3	Intake of oats plus linseed oil significantly exceeds (at 1% level) those of barley and wheat.
D (10 rats)	Barley plus linseed oil .. 13·1 Oats .. .. 80·5 Wheat .. 6·4	Intake of oats significantly exceeds (at 1% level) those of barley plus linseed oil and wheat.

The evaluation of any increases in collective intake due to the addition of attractants to foods is a field study.

Colouring of Foods.—Yellow, red, green, blue, and violet colouring agents have been used with various foods in controlled experiments. Colour has no significant effect on intake or on food selection by rats. In Queensland it is compulsory by law to colour any poison used in rat eradication; the author generally uses methylene blue for this purpose. Borden (1941) has listed Sudan red III. and Sudan red IV. as suitable for direct use with oils.

Addition of Poisons to Favoured Foods.—The addition to favoured foods of any of the poisons tested depresses intake. For rat species indigenous to Queensland canefields no method of masking the presence of poisons in food is known. Change of food or addition of flavourings does not alter depression of intake due to poisons; intake, in general, can be varied only by altering poison strength. There are a few exceptions, the reason for which is chiefly mechanical. For example, yellow phosphorus paste, and poisons with poor

toxicity, such as barium carbonate, are more efficient when used in grain derivatives than when used with whole grain; also, with some poisons at weak poison strength, there is a tendency for depression of intake to be relatively larger with finely-ground grain derivatives, such as wheatmeal, prepared food, and flour, than with whole grain. This is of little importance, for in these instances when intake approaches the lethal dose the intake of poisoned food is not influenced by the mechanical condition of the food.

Rat Preference for Different Parts of the Grain.—When grain such as wheat is offered to a house mouse (*Mus musculus*) population larger than is necessary to deal with the weight of grain supplied, approximately 25 per cent. by weight of the grain is not eaten. The leavings are mostly grain shells. The indigenous murine species in canefields tend to eat the whole of each grain separately and completely. When the amount of grain approaches that necessary to feed any given population, leavings are negligible. Gard (1935) found that Queensland canefields species did not peel off the skin of strychnine-coated wheat to avoid the poison. Often the harder part of the large maize grain is discarded when first encountered, but eventually practically all the grain is eaten.

Intakes of Favoured Foods in the Presence of Sugar Cane.—The two-food preference test shown in Table 4 illustrates the indeterminate results obtained in a small test cage when sugar cane was one of the foods offered.

Table 4.

Showing Intakes of Favoured Foods in the Presence of Sugar Cane.

Rat No.	Foods Offered.	Intake. g.	Standard Intake. g./g.	Weight of Rat (g.), Species, and Sex.
562	Sugar cane ..	10·0	·303	33 ; *M. littoralis* ; M.
	Wheat	3·43	·104	
563	Sugar cane ..	5·5	·204	27 ; *M. littoralis* ; F.
	Wheat	0·0	..	
564	Sugar cane ..	5·5	·063	87 ; *R. conatus* ; F.
	Wheat	3·79	·044	
565	Sugar cane ..	30·5	·368	83 ; *R. conatus* ; F.
	Wheat	0·0	..	
566	Sugar cane ..	9·0	·098	92 ; *R. conatus* ; M.
	Wheat	6·0	·065	
567	Sugar cane ..	8·0	·103	77½ ; *R. conatus* ; F.
	Wheat	2·05	·027	

Secondary Foods.

When a selection of secondary foods is offered over a test period, the total food intake does not exceed that of the best of them when it is presented alone. The intake of a secondary food is not increased by first starving the test animals. Attempts to increase the mean standard intake of a secondary food by adding substances such as raw linseed oil, maize oil, wheat oil, bacon fat oil, coconut oil, various other vegetable oils, and diacetyl were unsuccessful.

Table 5.

SHOWING TEST RESULTS WITH ARSENIC IN PREPARED FOOD.

Rat No.*	Poison Strength.	Poisoned Food. Intake. g.	Poisoned Food. Standard Intake. g./g.	Poison. Intake. mg.	Poison. Standard Intake. mg./kg.	Date Food Offered.	Date of Death.†	Weight (g.), and Sex of Rat (*R. conatus*).	Remarks.
521	1 in 20	0·29	·003	14·5	129·1	Nov. 24	..	106 ; M.	
522	1 in 20	0·86	·007	43·0	350·0	Nov. 24	Nov. 25	123 ; M.	Dead by 9 a.m. Nov. 25.
523	1 in 20	0·82	·007	41·0	343·1	Nov. 24	Nov. 25	119½ ; M.	Dead by 9 a.m. Nov. 25.
524	1 in 20	0·44	·004	22·0	220·0	Nov. 24	Nov. 25	100 ; M.	Died about 4 p.m. Nov. 25.
526	1 in 20	0·47	·005	23·5	252·7	Nov. 24	Nov. 25	93 ; M.	Dead by 9 a.m., Nov. 25.
527	1 in 20	0·98	·009	49·0	437·5	Nov. 24	Nov. 25	112 ; M.	Dead by 9 a.m., Nov. 25.
528	1 in 20	0·69	·008	34·5	420·8	Nov. 24	Nov. 25	82 ; M.	Dead by 9 a.m., Nov. 25.
529	1 in 20	0·44	·005	22·0	226·9	Nov. 24	Nov. 25	97 ; F.	Dead by 9 a.m., Nov. 25.
530	1 in 20	nil	..	..	..	Nov. 24	..	127 ; M.	
531	1 in 20	0·05	·0006	2·5	32·0	Nov. 24	..	78 ; F.	Very sick on Nov. 25 ; recovered.
532	1 in 20	nil	..	..	..	Nov. 24	..	90 ; F.	
533	1 in 20	0·50	·004	25·0	192·3	Nov. 24	Nov. 25	130 ; M.	Died about 5 p.m., Nov. 25.
534	1 in 20	0·33	·004	16·5	185·4	Nov. 24	Nov. 25	89 ; F.	Dead by 9 a.m., Nov. 25.
R 54	1 in 100	4·07	·034	40·7	339·2	July 19	..	120 ; M.	
R 55	1 in 100	3·94	·038	39·4	380·7	July 19	..	103½ ; F.	
59	1 in 100	3·51	·024	35·1	242·0	July 19	July 20	145 ; M.	
R 60	1 in 100	2·58	·024	25·8	243·4	July 21	..	106 ; F.	
73	1 in 100	6·05	·051	60·5	506·3	July 27	July 29	119½ ; M.	
74	1 in 100	6·65	·082	66·5	816·0	July 27	July 28	81½ ; F.	
R 75	1 in 100	1·36	·013	13·6	133·3	July 27	..	102 ; M.	
82	1 in 100	3·93	·024	39·3	238·9	July 27	..	164½ ; M.	
R 56	1 in 400	4·49	·032	11·2	78·9	July 19	..	142 ; M.	
R 58	1 in 400	3·07	·025	7·7	63·1	July 19	..	122 ; M.	
R 61	1 in 400	0·69	·006	1·7	15·5	July 21	..	110 ; M.	
R 62	1 in 400	2·61	·034	6·5	84·4	July 21	..	77 ; F.	
R 63	1 in 400	11·52	·083	28·8	207·2	July 21	..	139 ; M.	
R 64	1 in 400	3·56	·036	8·9	89·9	July 21	..	99 ; F.	
R 65	1 in 400	1·71	·014	4·3	34·1	July 21	..	126 ; M.	
R 54A	1 in 100	1·71	·014	17·1	142·5	July 26	..	..	Weight 120 g. on 26th ; 112 g. on 27th.
R 54B	1 in 200	3·15	·026	15·75	129·6	Aug. 5	..	121½	
R 54C	1 in 50	1·58	·013	31·0	255·2	Aug. 10	..	..	Weight 117 g. on 11th.
R 55A	1 in 100	5·73	·051	57·3	507·1	July 26	July 27	113	
R 56A	1 in 100	1·56	·010	15·6	104·0	July 26	..	150	
R 56B	1 in 100	2·54	·017	25·4	169·3	July 28	..	..	Weight 130 g. on 28th.
R 56C	1 in 200	0·52	·003	2·6	17·3	Aug. 5	..	..	Weight 133 g. on 6th.
R 58A	1 in 100	1·09	·008	10·9	79·6	July 26	..	137	Weight 129 g. on 27th.
R 58B	1 in 100	0·54	·004	5·4	39·5	July 27	..	..	
R 60A	1 in 400	8·64	·082	21·6	192·5	July 26	..	..	Weight 100½ g. on 26th ; 92 g. on 27th.
R 60B	1 in 200	2·11	·020	10·5	99·1	Aug. 5	..	..	Weight 100 g. on 5th ; 94 g. on 6th.
R 60C	1 in 200	2·72	·023	13·6	116·2	Aug. 10	..	117	
R 60D	1 in 50	2·00	·017	39·2	335·1	Aug. 11	..	..	Weight 93 g. on 11th.
R 60E	1 in 50	1·18	·010	29·0	248·0	Aug. 12	..	..	
R 61A	1 in 100	4·50	·040	45·0	401·8	July 26	..	112	Weight 102 g. on 27th
R 62A	1 in 100	1·92	·021	19·2	207·6	July 26	..	92½	Weight 67½ g. on 27th.
R 63A	1 in 100	4·59	·031	45·9	310·1	July 26	..	148	Weight 137 g. on 27th.
R 64A	1 in 400	4·52	·046	11·3	114·1	July 26	..	..	
R 64B	1 in 100	6·45	·065	64·5	651·6	July 28	July 29	..	
R 65A	1 in 400	2·70	·021	6·75	53·6	July 26	..	..	Weight 120 g. on 27th.
R 65B	1 in 400	3·91	·031	9·77	77·5	July 28	..	..	Weight 122 g. on 28th.
R 65C	1 in 200	0·42	·003	2·1	16·2	Aug. 5	..	129½	Weight 115 g. on 6th.
R 65D	1 in 200	3·09	·022	15·5	112·3	Aug. 10	..	138	Weight 129 g. on 11th.
R 65E	1 in 50	5·03	·036	98·6	714·5	Aug. 11	..	..	Weight 118 g. at 5 p.m. on 11th.
R 65F	1 in 200	0·25	·002	1·25	9·1	Aug. 12	..	..	Weight 104 g. on 13th.

* R before rat number denotes that the specimen will be, or is being, returned for further test. Letter after rat number denotes the return: A for first, B for second, and so on.

† All rats not reported dead were used at later dates for other purposes.

POISONS.

Arsenic (As_2O_3).

According to Wright (1936) the toxicity of As_2O_3 as a rat poison depends somewhat on the fineness of its state of subdivision; when taken in coarse lumps its toxicity is greatly reduced. Munch and Silver (1931), using wild rats and white rats, reported the minimum lethal dose of As_2O_3 (*i.e.*, "the quantity of poison that caused the death of all test animals, or practically all, within the period of five days") to be 100 mg./kg. Other records of As_2O_3 toxicities in rat baits are in the form of amounts of particular baits which will kill rats.

In these experiments a very finely powdered As_2O_3—Merck's reagent quality arsenic trioxide—was used in prepared food. At a poison strength of 1 in 20 the M.L.D., at the initial intake, was 100± 10 mg./kg. and the mean standard intake of poisoned food was ·004± ·0005 g./g. This means that the incorporation of arsenic trioxide depressed food intake by approximately 95 per cent., which supports the observation by Gard (1935) that arsenic with wheat proved quite unattractive to Queensland cane rats.

Table 5 is a series of relevant test results selected at random. Following the intake of sub-lethal doses the arsenic-food intake is still further reduced. A lethal dose during one test period is usually required to cause death.

Reductions in poison strength increase intakes, but the kills are even poorer than at 1 in 20. Figures in Table 5 show that large amounts of arsenic may be taken by some rats in weak poison mixtures, either at one feed or over a period, without causing death.

Appreciable increases in poison strengths above 1 in 20 serve no useful purpose; arsenic-food intakes are often negligible and total kill is decreased.

Using As_2O_3 under optimum conditions—*i.e.*, with the poison mixed in a dry favoured food, and in cages, where the chances of a maximum feed at the first offer are good—a poison intake of not more than twice the M.L.D. can be expected. This is too small a margin to ensure success in the field. The cage experiment results indicate that any degree of success in application control work with this poison will be attained only when it is offered at prebaited feeding stations.

Barium as Barium Carbonate.

Schwartze (1920) remarked that "the literature contains no references to work dealing with the toxicity of barium carbonate to rats, in spite of the fact that many articles give directions for its use as a rat poison and discuss its toxicity to other animals." This author, using *Rattus norvegicus* and administering $BaCO_3$ in starch paste suspension by a stomach tube, found "630 to 750 mg. per kilo . . . . to be the least amount which could be considered efficient," and "the occasional survival of an animal from a large dose would indicate that a 100 per cent. mortality could not be expected." Feeding experiments confirmed these toxicity results and food intakes were such that

Table 6.

SHOWING TEST RESULTS WITH BARIUM CARBONATE IN PREPARED FOOD.

Rat No.*	Poison Strength.	Poisoned Food.		Poison.		Date Food Offered.	Date of Death.†	Weight (g.), and Sex of Rat (*R. conatus*).	Remarks.
		Intake. g.	Standard Intake. g./g.	Intake. mg.	Standard Intake. mg./kg.				
R 249	1 in 40	4·91	·062	122·8	1,554·0	Sept. 7	..	79 ; F.	
R 250	1 in 40	3·41	·032	85·3	789·9	Sept. 7	..	108 ; M.	
R 251	1 in 40	4·96	·048	124·0	1,204·0	Sept. 7	..	103 ; F.	
R 252	1 in 20	1·75	·023	87·5	1,136·4	Sept. 7	..	77 ; F.	
R 253	1 in 20	1·25	·011	62·5	563·1	Sept. 7	..	111 ; M.	
R 254	1 in 20	1·92	·020	96·0	980·0	Sept. 7	..	98 ; F.	
255	1 in 20	2·97	·039	148·5	1,928·6	Sept. 7	Sept. 9	77 ; F.	Sick on 8th.
R 246A‡	1 in 10	8·23	·065	823·0	6,480·4	Sept. 14	..	127 ; M.	Weight 114 g. on 14th ; 106 g. on 15th.
R 245A‡	1 in 10	2·38	·033	238·0	3,282·0	Sept. 14	..	72½ ; F.	Weight 68½ g. on 15th.
258	1 in 10	3·83	·035	383·0	3,546·3	Sept. 14	Sept. 15	108 ; M.	
269	1 in 5	2·52	·029	504·0	5,727·3	Sept. 22	Sept. 23	88 ; F.	Dead weight 76 g.
270	1 in 5	1·66	·015	332·0	3,018·2	Sept. 22	..	110 ; M.	Weight 90 g. on 23rd ; slightly sick.
271	1 in 5	0·71	·006	142·0	1,101·0	Sept. 22	Sept. 23	129 ; M.	Dead weight 127 g.
272	1 in 5	0·94	·008	188·0	1,649·2	Sept. 22	Sept. 23	114 ; M.	Dead weight 110 g.
273	1 in 5	1·05	·013	210·0	2,561·0	Sept. 22	Sept. 23	82 ; F.	Dead weight 81 g.
274	1 in 5	0·69	·007	138·0	1,460·4	Sept. 22	Sept. 23	94½ ; M.	Dead weight 91 g.
R 275	1 in 10	2·93	·030	293·0	3,021·0	Sept. 23	..	97 ; F.	Weight 90½ g. on 24th ; slightly sick.
276	1 in 10	1·04	·010	104·0	954·1	Sept. 23	..	109 ; F.	Weight 100 g. on 24th.
R 277	1 in 10	1·84	·022	184·0	2,217·0	Sept. 23	..	83 ; F.	Weight 78½ g. on 24th.
278	1 in 10	0·32	·003	32·0	309·2	Sept. 23	Sept. 24	103½ ; M.	Dead weight 96 g.
279	1 in 10	0·71	·008	71·0	763·4	Sept. 23	Sept. 24	93 ; M.	Dead weight 89 g.
R 280	1 in 10	0·15	·001	15·0	107·1	Sept. 23	..	140 ; M.	Weight 134 g. on 24th.
R 281	1 in 20	0·54	·004	27·0	217·8	Sept. 23	..	124 ; M.	Weight 111½ g. on 24th.
R 282	1 in 20	0·46	·005	23·0	262·9	Sept. 23	..	87½ ; F.	Weight 82 g. on 24th.
286	1 in 20	2·81	·025	140·5	1,248·9	Sept. 23	Sept. 24	112½ ; M.	Dead weight 110½ g.
R 249A	1 in 20	2·76	·033	138·0	1,662·7	Sept. 14	..	83	Weight 79 g. on 15th.
R 250A	1 in 10	0·25	·003	25·0	231·5	Sept. 14	..	..	
R 251A	1 in 20	2·75	·026	137·5	1,322·0	Sept. 14	..	104	
R 252A	1 in 10	2·39	·031	239·0	3,103·9	Sept. 14	Sept. 15	..	
R 253A	1 in 20	3·34	·030	167·0	1,504·5	Sept. 14	..	..	Weight 102 g. on 15th ; slightly sick.
R 254A	1 in 10	3·95	·040	395·0	3,950·0	Sept. 14	..	100	Weight 94 g. on 15th.
R 275A	1 in 5	2·59	·026	518·0	5,232·3	Oct. 5	..	99	Weight 92 g. on 6th.
R 275B	1 in 20§	3·10	·032	155·0	1,565·7	Sept. 29	..	..	Weight 93 g. on 29th ; 83½ g. on 30th.
R 277A	1 in 40§	2·54	·026	63·5	765·1	Sept. 29	..	..	
R 281A	1 in 5	1·27	·010	254·0	2,048·4	Sept. 29	..	..	Weight 111½ g. on 29th ; 106 g. on 30th.
R 282A	1 in 40§	2·54	·029	63·5	725·7	Sept. 29	Sept. 30	..	Weight 84½ g. on 29th ; 69 g. on 30th.

* R before rat number denotes that the specimen will be, or is being, returned for further test. Letter after rat number denotes the return : A for first, B for second.

† All rats not reported dead were used at later dates for other purposes.

‡ These return tests are with rats used previously with other poisons.

§ $BaCl_2$ substituted for $BaCO_3$.

it was concluded that "the barium carbonate added to the diet was perfectly palatable." Test animals had been starved for 12 to 24 hours before being fed poison in order to ensure an empty stomach and a sharp appetite.

Wright (1936) considered that $BaCO_3$ is more effective when taken by a hungry animal at the commencement of feeding than if taken later on an already full stomach. Munch and Silver (1931), probably working with

R. norvegicus (starved 12-24 hours), reported 750 mg./kg. for barium carbonate as their comparative toxicity figure. Pemberton (1925) reported cage experiments with $BaCO_3$ mixed dry with rolled oats, wheat flakes, or dry flour in a ratio of one part of poison to 3-6 parts of food. Intake was small and a poor percentage of deaths occurred.

Merck's reagent quality $BaCO_3$ was used in prepared food in the author's experiments, selected results of which are given in Table 6. The figures given in Table 7 illustrate the intake variations which occur with different poison strengths.

Table 7.

Showing Mean Standard Intakes of Barium Carbonate in Prepared Food.

Poison Strength.	Mean Standard Intakes (g./g.) of Prepared Food—Barium Carbonate.
1 in 5	·009 ± ·00025
1 in 10	·020 ± ·C047
1 in 20	·021 ± ·0025
1 in 40	·047 ± ·005

After some preliminary tests it became apparent that the rat population being used by the author could be separated into three classes—viz., (*a*) those which could be killed by $BaCO_3$, amounting to approximately 70 per cent.; (*b*) rats which could be poisoned only with considerable difficulty, representing about 22 per cent.; and (*c*) the remaining 8 per cent. which could not be killed with $BaCO_3$ under the conditions of the experiments. A typical example of class (*c*) is rat No. 275 (Table 6). At later dates this rat was given further unweighed food containing $BaCO_3$ at high strengths and survived.

The M.L.D. of barium carbonate for class (*a*) rats is 700± 75 mg./kg. and it does not vary with poison strength to the same extent as does the M.L.D. of As_2O_3. In cages and with poison strengths of from 1 in 3 to 1 in 5 the maximum poison intake attainable using dry prepared food is two to three times the M.L.D. Eskey (1934) has pointed out that "barium carbonate could be used in only 5 per cent. strength with whole grain, as larger amounts would not adhere to the grain." In applied control work, therefore, barium carbonate cannot be used effectively with whole grain. Usually the poison is mixed with grain derivatives and in Queensland canefields barium biscuits have been used. These biscuits consist of one or more grain derivatives mixed with barium carbonate. In the mixing the grain material is wetted with water and then dried, and this reduces the food base bait of a barium biscuit to the status of a secondary food (see page 7) considerably diluted by a large proportion of poison. In cage experiments with barium biscuits, intakes were generally negligible and the few deaths caused by them could be considered as accidental, since in any rat population there is always a small percentage exhibiting abnormal behaviour.

Barium as Barium Chloride.

Wright (1936), in discussing barium carbonate, stated: "It is insoluble in water, and as such is probably non-toxic. It is readily converted, in the presence of dilute hydrochloric acid, into the soluble and highly-toxic barium chloride. Its toxicity depends upon the presence of hydrochloric acid in the stomach . . . ."

Schwartze (1920) using *Rattus norvegicus* and the ordinary crystallized salt, $BaCl_2 \cdot 2H_2O$, found the oral lethal dose to be from 355 g. to 533 g. per kilo. When comparing his barium carbonate and barium chloride toxicity experimental results this author stated: "On the basis of barium content, this preparation of barium carbonate was from 57 to 75 per cent. as potent as barium chloride. In other words, approximately two-thirds of the carbonate was utilised in poisoning the animal."

Table 8 is a selection of test results obtained with Merck's reagent quality $BaCl_2$ in prepared food. At all poison strengths with economic possibilities intakes are poor and irregular. Best results are obtained at a poison strength of 1 in 20 but the M.L.D. of 600 ± 50 mg./kg. is, in many instances, barely covered. As with barium carbonate, many rats do not die after comparatively large intakes of barium chloride.

Table 8.

SHOWING TEST RESULTS WITH BARIUM CHLORIDE IN PREPARED FOOD.

Rat No.*	Poison Strength.	Poisoned Food.		Poison.		Date Food Offered.	Date of Death.†	Weight (g.), and Sex of Rat (*R. conatus*).	Remarks.
		Intake. g.	Standard Intake. g./g.	Intake. mg.	Standard Intake. mg./kg.				
R 241	1 in 50	2·79	·020	54·7	388·0	Sept. 6	..	141 ; M.	Weight 129½ g. on 7th.
R 242	1 in 50	0·40	·004	8·0	73·4	Sept. 6	..	109 ; F.	
243	1 in 50	1·30	·011	25·9	223·3	Sept. 6	Sept. 7	116 ; F.	
R 245	1 in 50	1·19	·017	23·8	330·6	Sept. 7	..	72 ; F.	Weight 67½ g. on 8th ; very sick.
R 246	1 in 50	1·35	·011	27·0	212·6	Sept. 7	..	127 ; M.	
247	1 in 50	5·64	·074	112·8	1,484·2	Sept. 7	Sept. 8	76 ; F.	
R 248	1 in 50	3·73	·028	74·6	565·2	Sept. 7	..	132 ; M.	
288	1 in 20	1·66	·035	83·0	603·6	Sept. 28	Sept. 30	137½ ; M.	Slightly sick on 29th ; accidentally killed.
289	1 in 20	4·95	·040	247·5	2,229·7	Sept. 28	Sept. 30	111 ; M.	Slightly sick on 29th.
290	1 in 20	1·55	·032	77·5	756·1	Sept. 28	Sept. 30	102½ ; F.	Very sick on 29th.
291	1 in 20	6·09	·051	304·5	2,719·0	Sept. 28	Sept. 30	112 ; M.	
292	1 in 20	4·08	·026	102·0	886·9	Sept. 28	Sept. 30	115 ; M.	
293	1 in 20	5·80	·058	145·0	1,007·0	Sept. 28	Sept. 29	144 ; M.	
294	1 in 20	5·08	·013	127·0	798·7	Sept. 28	Sept. 30	159 ; M.	Very sick on 29th.
295	1 in 20	5·41	·032	135·3	1,276·4	Sept. 28	Sept. 29	106 ; M.	
296	1 in 20	3·11	·017	77·7	653·0	Sept. 28	..	119 ; M.	
297	1 in 20	5·17	·010	129·3	1,453·0	Sept. 28	..	89 ; F.	
R 366	1 in 10	0·28	·002	28·0	189·8	Oct. 21	..	147½ ; M.	
R 367	1 in 10	0·29	·003	29·0	281·6	Oct. 21	..	103 ; F.	
R 368	1 in 10	2·25	·026	225·0	2,571·0	Oct. 21	..	87½ ; F.	
369	1 in 10	0·27	·003	27·0	300·0	Oct. 21	..	90 ; M.	
R 374	1 in 10	2·85	·028	285·0	2,794·1	Oct. 22	..	102 ; M.	
375	1 in 10	1·12	·013	112·0	1,325·4	Oct. 22	..	84½ ; F.	
376	1 in 10	2·06	·025	206·0	2,543·2	Oct. 22	..	81 ; F.	Very sick on 23rd.
R 377	1 in 10	1·00	·012	100·0	1,204·8	Oct. 22	..	83 ; F.	

* R before rat number denotes return tests with rats used previously with other poisons.

† All rats not reported dead were used at later dates for other purposes.

Schwartze (1920) cited Storer as reporting that "calcium carbonate (whiting) protects rats and mice against barium carbonate as well as lead carbonate poisoning." This author commented that "there is, however, some uncertainty about these experiments, in the absence of definite quantitative poison and food-intake data." Although such references in literature are rare, the concept that on occasions certain foods protect rats from poison is freely discussed by some of these interested in the control of rats in Queensland canefields: $BaCO_3$ is usually associated with these discussions. Although relevant experiments by the author are illustrated in this paper by $BaCl_2$ test results only, rats suitably conditioned exhibit similar behaviour after ingesting $BaCO_3$. Rats fed only on sugar cane during the week previous to testing showed improved intakes of barium but the relatively large intakes of the poison were never lethal. Table 9 is the results of two series: rats Nos. 319-330 reacted normally when fed $BaCl_2$ after a fortnight of dormitory food. The selection of sugar cane as the test material was based on the conversion of $BaCO_3$ to $BaCl_2$ in the rat's stomach and this material provides the largest nightly liquid intake. Similar feeding of rats prior to offering the other poisons used in the experiments does not affect intake of lethal doses.

From cage experimental data it is concluded that $BaCO_3$ and $BaCl_2$ are extremely inefficient rat poisons for use in Queensland canefields.

Table 9.

Showing Effect of Feeding on Sugar Cane on Toxicity of Barium Chloride in Prepared Food.

Rat No.	Poison Strength.	Poisoned Food.		Poison.		Date Food Offered.	Date of Death.	Weight (g.), Species, and Sex of Rat.	Remarks.
		Intake. g.	Standard Intake. g./g.	Intake mg.	Standard Intake. mg./kg.				
319	1 in 15	8·02	·072	510·3	4,595·0	Oct. 12	..	111; *conatus*; M.	These rats fed on sugar cane only for the week previous to Oct. 12th.
320	1 in 15	2·66	·036	166·3	2,251·8	Oct. 12	..	74; *conatus*; F.	
321	1 in 15	2·62	·027	163·8	1,688·7	Oct. 12	..	97; *conatus*; F.	
322	1 in 15	0·89	·012	55·6	722·1	Oct. 12	..	77; *culmorum*; F.	
323	1 in 15	4·34	·046	271·3	2,886·2	Oct. 12	..	94; *conatus*; M.	
324	1 in 15	4·39	·055	274·4	3,541·6	Oct. 12	..	79½; *conatus*; F.	
325	1 in 30	0·43	·009	13·9	286·6	Oct. 14	..	48½; *M. littoralis*; M.	These rats fed on sugar cane only for the week previous to Oct. 14th.
326	1 in 30	0·41	·003	13·3	110·9	Oct. 14	..	120; *conatus*; M.	
327	1 in 30	4·00	·042	129·1	1,344·8	Oct. 14	..	96; *conatus*; M.	
328	1 in 30	1·83	·019	59·0	627·7	Oct. 14	..	94; *conatus*; M.	
329	1 in 30	3·74	·037	120·6	1,118·2	Oct. 14	..	101½; *conatus*; F.	
330	1 in 30	4·34	·056	141·0	1,831·2	Oct. 14	..	77; *conatus*; F.	

Phosphorus.

No published records of detailed cage experiments with yellow phosphorus as a rat poison are known to the author. Boulenger (1919) stated: "Phosphorus, although obviously easy to detect, proved to be an attractive bait, and far more so than arsenic; unlike the latter, however, it does not, especially in summer, retain its toxic properties for more than a few days." Wright (1936) considered that yellow phosphorus, being insoluble in water, "is absorbed with difficulty and comparatively large quantities can be taken

without ill-effect. Absorption is facilitated when it is in a finely-divided state. It is readily soluble in fats and oils and when given in such a medium is highly toxic." Montserin (1937) found phosphorus match-heads dissolved in banana to be more efficient against the Trinidad tree rat, in both cage and field trials, than various other poisons, including thallous sulphate. Borden (1941), using "Rat-nip," a commercial phosphorus preparation, at varying concentrations in oats obtained about a 65 per cent. kill, but concluded that "if rats can be persuaded to eat even a small quantity of a 40 per cent. mixture of Rat-nip in a dry carrier bait, it will be very deadly to them." Furthermore, "the toxicity of Rat-nip seems to be reduced if it is allowed to dry in a thin layer. This is explained by the fact that yellow phosphorus oxidises slowly to red phosphorus (non-poisonous) when exposed to the air."

Yellow phosphorus as a rat poison is generally used as a paste, for which there are numerous recipes differing only in detail. That of Cilento (1934) for the standard 1 in 112 paste used in Queensland is as follows:—

> "Phosphorus, 4 oz.; golden syrup, 21 lb.; arrowroot, 3 lb.; flour, 3 lb.; water, 12 oz. Weigh the golden syrup into an enamelled basin. Add the phosphorus quickly, and cover it at once with syrup to prevent it from taking fire. Pour the water on top of the syrup. Heat the mixture carefully to 120 deg. Fahr. in a water bath until the phosphorus is melted. Meanwhile mix the flour and arrowroot together, and, after thorough incorporation, pass the mixture through a fine sieve. When the syrup is heated through and the phosphorus dissolved, remove from the water bath. Stir quickly with a flat wooden spatula, adding the flour mixture gradually. Stir and beat with the spatula in order to divide the phosphorus as finely as possible. Continue to stir and beat the mixture till it is nearly cold, adding any colouring or flavouring which may be desired. Store the mixture when made in airtight tins."

Pastes made by this method store well. For canefield species cornflour or more flour can be used in place of arrowroot. Garlough (1938) mentioned a fire hazard when using phosphorus compounds as rat poisons. The igniting of phosphorus when spreading poorly made pastes on the bait carrier has been experienced; such happenings are completely eliminated when instructions for making the pastes have been followed carefully and when the pastes are well stirred before using.

Table 10.

Showing Mean Standard Intakes and Kill of Yellow Phosphorus Paste in Prepared Food.

Proportion of Phosphorus in Paste.	Ratio of Paste to Food.	Poison Strength.	Mean Standard Intake. g./g.	Percentage Kill.
1 in 112	2 : 5	1 in 395	·004 ± ·0003	100
1 in 250	2 : 3	1 in 625	·0025 ± ·0002	100
1 in 500	1 : 1	1 in 1,000	·006 ± ·001	100
1 in 1,000	1 : 1	1 in 2,000	·020 ± ·003	50

Poison strengths of yellow phosphorus may be varied by altering the proportions of poison in the paste and/or the proportions of pastes mixed with food. Intake depression may be brought about by diluting the favoured food. Intakes of poison in foods poisoned with pastes of various strengths prepared according to Cilento's method are given in Table 10.

Table 11.

Showing Test Results with Yellow Phosphorus Paste (1 in 112) with Prepared Food.

Rat No.*	Poisoned Food.				Poison.		Date Poisoned Food Offered. (Mixed Oct. 21)	Date of Death.	Weight (g.), and Sex of Rat (*R. conatus*).	Remarks.
	Weight of Prepared Food. g.	Weight of Phosphorus Paste. (1 in 112). g.	Intake. g.	Standard Intake. g./g.	Intake. mg.	Standard Intake. mg./kg.				
355	5·26	2·73	0·27	·002	0·84	5·3	Oct. 21	..	160 ; M.	
356	5·69	2·77	0·81	·006	2·35	16·1	Oct. 21	Oct. 22	146 ; M.	
357	4·53	3·56	0·27	·002	1·05	9·1	Oct. 21	Oct. 22	116 ; M.	
358	5·50	3·78	1·02	·008	3·68	28·9	Oct. 21	Oct. 22	127½ ; F.	
C 42	5·26	2·73	0·46	·007	1·44	21·2	Oct. 22	..	68 ; F.	
C 40	5·69	2·77	0·51	·005	1·48	13·1	Oct. 22	Oct. 24	113 ; M.	Very sick on 23rd.
C 41	4·53	3·56	0·05	·0008	0·195	3·0	Oct. 22	Oct. 24	66 ; F.	
373	5·50	3·78	0·28	·004	1·01	13·3	Oct. 22	Oct. 24	76 ; F.	
C 45A	5·26	2·73	2·44	·046	7·58	141·7	Oct. 25	Oct. 28	53½ ; M.	
366A	5·69	2·77	0·02	·0001	0·58	3·9	Oct. 25	Oct. 26	148 ; M.	
368A	4·53	3·56	1·09	·012	4·24	48·5	Oct. 25	Oct. 26	87½ ; F.	
R 374A	5·50	3·78	Nil	..	..	..	Oct. 25	..	102 ; M.	
370A	5·26	2·73	1·82	·025	5·65	78·5	Oct. 26	Oct. 30	72 ; F.	
381	5·69	2·77	3·65	·055	10·58	160·3	Oct. 26	Oct. 29	66 ; F.	
382	4·53	3·56	2·20	·014	8·59	55·8	Oct. 26	Oct. 29	154 ; F.	
383	5·50	3·78	0·45	·004	1·63	15·1	Oct. 26	Oct. 31	108 ; F.	
C 52	5·26	2·73	0·20	·003	0·62	8·0	Oct. 28	Nov. 2	77½ ; F.	
C 54	5·69	2·77	Nil	..	..	..	Oct. 28	..	149 ; M.	
C 51	4·53	3·56	0·59	·006	2·30	24·2	Oct. 28	Nov. 2	95 ; F.	
401	5·50	3·78	0·29	·004	1·05	13·5	Oct. 28	Oct. 29	78 ; F.	
406	5·26	2·73	0·26	·002	0·81	6·9	Oct. 29	Nov. 4	118 ; M.	
407	5·69	2·77	1·66	·016	4·81	45·0	Oct. 29	Oct. 31	107 ; M.	
408	4·53	3·56	0·27	·027	1·05	10·6	Oct. 29	Nov. 2	99 ; F.	
379A	5·50	3·78	3·09	·049	11·16	177·2	Oct. 29	Oct. 30	63 ; M.	
402A	5·26	2·73	1·20	·015	3·73	46·1	Nov. 3	Nov. 7	81 ; F.	
R 399A	5·69	2·77	0·19	·001	0·55	3·5	Nov. 3	..	159 ; M.	
385A	4·53	3·56	0·49	·007	1·91	26·2	Nov. 3	Nov. 6	73 ; F.	
R 384A	5·50	3·78	0·43	·004	1·55	12·8	Nov. 3	..	121 ; F.	Gave birth to 4 young on 8th.

* R before rat number denotes that the specimen will be, or is being, returned for further test. Letter after rat number denotes the return : A for first.

According to Wright (1936) the action of phosphorus on a rat's system is "similar to that of arsenic, except that it is slower." Phosphorus also resembles arsenic in that the M.L.D. varies somewhat with the poison strength. At a strength of 1 in 2,000 (see Table 10) the M.L.D. is 10 mg./kg., and, at strengths most suitable for economic purposes—*i.e.*, from 1 in 200 to 1 in 400—

Table 12.

SHOWING TEST RESULTS WITH YELLOW PHOSPHORUS PASTE (1 IN 112) WITH GRAIN.

Rat No.	Date Offered.	Date of Death.	Time Taken to Die.	Remarks.
	Wheat and paste not mixed ; manufactured Oct. 19.			
337	Oct. 19 ..	Oct. 24 ..	4½–5 days ..	Did not seem to touch poison, but ate most of wheat.
338	Oct. 19 ..	Oct. 23 ..	3½–4 days ..	
339	Oct. 19 ..	Oct. 23 ..	3½–4 days ..	
	Wheat and paste mixed ; manufactured Oct. 19.			
340	Oct. 19 ..	Oct. 20 ..	Under 12 hours	Negligible take.
341	Oct. 19 ..	Oct. 21 ..	1½–2 days ..	
342	Oct. 19 ..	Oct. 23 ..	3½–4 days ..	
343	Oct. 20 ..	Oct. 23 ..	2½–3 days ..	
344	Oct. 20 ..	..	..	
345	Oct. 20 ..	Oct. 21 ..	Under 12 hours	
346	Oct. 21 ..	..	..	Did not eat.
347	Oct. 21 ..	..	..	
348	Oct. 21 ..	..	..	
349	Oct. 22 ..	..	..	Did not eat.
350	Oct. 22 ..	..	..	
351	Oct. 22 ..	Oct. 23 ..	Under 12 hours	
352	Oct. 23 ..	Oct. 24 ..	12–18 hours ..	
353	Oct. 23 ..	..	..	Did not eat.
354	Oct. 23 ..	..	..	
	Wheat and paste mixed on Oct. 18 ; lightly sprayed with linseed oil before each offering.			
362	Oct. 21 ..	Oct. 24 ..	2½–3 days ..	Both sick on Oct. 23.
363	Oct. 21 ..	Oct. 24 ..	2½–3 days ..	
364	Oct. 22 ..	..	..	
365	Oct. 22 ..	..	..	
C 67	Oct. 23 ..	..	..	
C 68	Oct. 23 ..	Oct. 28 ..	4½–5 days ..	
C 69	Oct. 24 ..	..	..	
C 70	Oct. 24 ..	..	..	

it is less than 1 mg./kg. The time elapsing between ingestion of poison and death is of particular importance in experiments with phosphorus as a rat poison. At a poison strength of 1 in 1,000 (as in Table 10) some deaths were recorded 4 to 7 days after poison intakes and at all poison strengths intakes close to the lethal dose may not cause death until as late as 11 days after ingestion. In many instances in cage experiments with phosphorus, deaths occur comparatively quickly despite large depression in food intake when using favoured foods. Actually the negligible takes and small intakes usually allow for a large multiple of the lethal dose and the quick deaths are due to overdosing. Table 11 illustrates the use of phosphorus paste with a dry ground

Table 13.

Showing Test Results with Yellow Phosphorus Paste (1 in 112) on Bread.

Rat No.	Date Offered.	Date of Death.	Time Taken to Die.	Remarks.
		Bait manufactured Aug. 2 and tinned.		
170	Aug. 17 ..	Aug. 18 ..	Under 12 hours	Negligible take.
171	Aug. 17 ..	Aug. 18 ..	Under 12 hours	
172	Aug. 17 ..	Aug. 18 ..	Under 12 hours	
173	Aug. 17 ..	Aug. 18 ..	Under 12 hours	
174	Aug. 17 ..	Aug. 18 ..	Under 12 hours	
175	Aug. 17 ..	Aug. 18 ..	Under 12 hours	
		Bait manufactured Aug. 17 and bagged.		
187	Aug. 25 ..	..	..	Did not eat.
188	Aug. 25 ..	Aug. 26 ..	Under 12 hours	Negligible take.
189	Aug. 25 ..	Aug. 26 ..	Under 12 hours	
190	Aug. 25 ..	Aug. 26 ..	Under 12 hours	
191	Aug. 25 ..	..	..	Did not eat.
192	Aug. 25 ..	Aug. 26 ..	Under 12 hours	Negligible take.
		Bait manufactured Aug. 17 and bagged; in field a day and a night before offering.		
207	Aug. 26 ..	Aug. 29 ..	2½–3 days ..	No apparent take.
208	Aug. 26 ..	Aug. 29 ..	2½–3 days ..	
209	Aug. 26 ..	Aug. 29 ..	2½–3 days ..	
210	Aug. 26 ..	Aug. 27 ..	Under 12 hours	
		Bait manufactured Nov. 25; in continuous rain for 24 hours prior to offering.		
546	Nov. 26 ..	Nov. 28 ..	1½–2 days ..	Apparently very poor take.
547	Nov. 26 ..	Nov. 28 ..	1½–2 days ..	
		Bait manufactured Aug. 2 and bagged.		
C.M. 36	Aug. 9 ..	Aug. 10 ..	Under 12 hours	*Melomys littoralis*.
C.M. 46	Aug. 9 ..	Aug. 10 ..	Under 12 hours	

favoured food and Table 12 with or on a whole grain. Examples have been included (Rats Nos. 364, 365, and C.67-C.70, Table 12) of the failure of the addition of linseed oil to increase unfavourable intakes (see page 7).

Table 13 is concerned with paste spread thinly on slices of bread approximately ½ inch thick. Individual baits were made by cutting these slices into dices about ½ inch square.

Phosphorus paste as a rat poison is essentially for use as a snap bait, and in cage experiments it is highly efficient over a wide range of conditions. The choice of a bait base with phosphorus depends on circumstances and, in many instances in Queensland canefields, the use of a favoured food would be unnecessary and wasteful even if practicable. Whole grain is not suitable as a bait base for phosphorus paste as the paste must be well mixed with the food: in the case of bread the thin spread is absorbed sufficiently for this purpose.

Table 14.

SHOWING RETENTION OF TOXICITY BY YELLOW PHOSPHORUS PASTE (1 IN 112) ON BREAD.

Rat No.	Date Offered.	Date of Death.	Time Taken to Die.	Remarks.
Bait manufactured Nov. 25; kept in field until Dec. 20.				
605	Dec. 21 ..	Dec. 26 ..	5 days	
606	Dec. 21 ..	Dec. 24 ..	3 days	
607	Dec. 21 ..	..	..	Did not eat.
Bait manufactured Nov. 25; kept in field until Dec. 20; crumbled, and syrup, flour and arrowroot added before offering.				
638	Jan. 25 ..	Jan. 28 ..	2½–3 days ..	
639	Jan. 25 ..	Jan. 30 ..	4½–5 days ..	
640	Jan. 25 ..	Jan. 29 ..	3½–4 days ..	
641	Jan. 25 ..	Jan. 29 ..	3½–4 days ..	
642	Jan. 25 ..	Jan. 31 ..	5½–6 days ..	
643	Jan. 25 ..	Jan. 28 ..	2½–3 days ..	
Bait manufactured Mar. 23 and bagged; ground and mixed with prepared food before offering.				
..	Sept. 12 ..	Sept. 14 ..	1½–2 days ..	
..	Sept. 12 ..	Sept. 17 ..	4½–5 days ..	
..	Sept. 12 ..	Sept. 17 ..	4½–5 days ..	
..	Sept. 12 ..	Sept. 15 ..	2½–3 days ..	
..	Sept. 12 ..	Sept. 20 ..	7½–8 days ..	
39/430	Oct. 30 ..	..	..	Standard intakes from ·030 g./g. to ·090 g./g.
39/431	Oct. 30 ..	Nov. 2 ..	2½–3 days ..	
39/432	Oct. 30 ..	Nov. 2 ..	2½–3 days ..	
39/433	Oct. 30 ..	..	..	
39/434	Oct. 30 ..	Nov. 3 ..	3½–4 days ..	
39/435	Oct. 30 ..	..	..	
39/436	Oct. 30 ..	..	..	Young born on Nov. 6.
Bait manufactured Mar. 23 and bagged.				
39/437	Oct. 30 ..	Nov. 3 ..	3½–4 days ..	
39/438	Oct. 30 ..	..	..	
39/439	Oct. 30 ..	Nov. 1 ..	2 days	
39/440	Oct. 30 ..	Nov. 2 ..	3 days	
39/441	Oct. 30 ..	..	..	

Table 11 also illustrates that phosphorus in prepared food is highly toxic for some days under cage conditions. Table 14, which consists of only a few of the relevant tests made, shows that the toxicity of the phosphorus bait is high for Queensland cane rats over lengthy periods of time. For other animals two examples may be given. Three weeks' old tinned phosphorus-bread baits were carelessly left on the first night of exposure near some 3 months' old chickens. Six died within four hours of picking at these baits. On another occasion three bandicoots were offered 25 phosphorus-bread baits five days after manufacture: although take was poor one weighing 1613 g. died within 12 hours. Where take is negligible and intake is not recorded it is possible that attractiveness and toxicity may have been confused in deciding the reason for non-deaths of rats when offering phosphorus baits. It is suggested that some of the earlier references to the quick loss of toxicity of a bait such as phosphorus-bread may be due to this cause.

Red Squill.

Munch, Silver and Horn (1929) reviewed the literature up to 1929 and supplied considerable cage and laboratory data on red squill. O'Connor, Buck and Fellers (1935) gave details on the standardization of red squill powders and further information on their properties, toxicities, and palatability. These groups of workers used white rats or *R. norvegicus* as test animals and from their observations the salient features of red squill as a rat poison may be stated as follows:—

1. It is generally accepted that squill as a poison is specific to rats. For other animals it is a powerful emetic; in addition, intake by other animals is usually insufficient to provide a lethal dose.
2. "Since red squill powders vary greatly in toxicity, a reliable method for standardising these powders is necessary" (O'Connor *et al.*).
3. "Because the toxic principle of red squill is not known, a chemical procedure as a means of standardising these powders cannot be used. It is necessary to resort to a biological procedure . . . ." (O'Connor *et al.*).
4. "Results obtained in 14 series confirm Claremont's findings that, on the average, less squill powder is required to kill wild rats than is required to kill white rats" (Munch *et al.*).
5. Based on food consumption data for *R. norvegicus*, Munch *et al.* considered squill preparations having a lethal dose at or below 1,000 mg./kg. to be sufficiently toxic for commercial purposes. These workers used 10 per cent. poison concentrations in most instances.
6. "Rats which recover from the effect of sub-lethal doses of red squill powder could rarely be induced to eat squill powder again, even after a lapse of several months. The same animals readily consumed baits containing alcohol or glycerol extracts of red squill" (O'Connor *et al.*).
7. "Red squill powder which has been in storage for 3 years showed no deterioration" (O'Connor *et al.*).

Several authors point out that the sex of the rat is a factor in the toxicity of red squill: it is half as toxic for male as for female rats. Lubitz, Levine and Fellers (1941) recommend "that standard assays of red squill be based on male rats rather than on female rats or rats of mixed sexes."

Three samples of red squill powder were used in the cage experiments, viz.:—

Sample A: Labelled "For Experimental Purposes";

Sample B: A greenish commercial material of French manufacture packed in tins;

Sample C: A commercial line packed in tins.

Munch, Silver and Horn (1929) reported that powder placed in screw-top cardboard mailing tubes for protection from the air, after six months to a year, "solidified into a hard cake, but no change in toxicity could be detected." The three samples used by the author were, when received, of the consistency of hardening putty. Thorough mixing with dry food was difficult. Three years later no appreciable change in toxicities could be detected but the powders had hardened and mixing was still more difficult.

At poison strengths of 1:50 in prepared food the M.L.D.'s and mean standard intakes of the three samples are as in Table 15.

Table 15.

SHOWING MEAN STANDARD INTAKES OF RED SQUILL POWDERS.

Sample.	M.L.D. mg./kg.	Mean Standard Intake g./g.
A	350 ± 50	·035 ± ·0032
B	550 ± 50	·030 ± ·0047
C	1,000 +	·050 ± ·0049

Neither M.L.D.'s nor kills are improved by mixing 2 per cent. by weight of finely ground glass in the squill poisoned food.

A population of mixed sexes was used as test animals. There was a tendency for males to require slightly larger lethal doses than females but it was not consistent over several series. On the other hand, the lethal dose of any poison for pregnant females, at the peak of virility, was often above the mean.

More detailed work was undertaken with Sample A at poison strengths of 1 in 10, 1:50 and 1:75 (see Tables 16 for a selection of series). Over this range the M.L.D. does not alter appreciably. At a strength of 1 in 10 there are always some rats (*e.g.*, Nos. 470, 471, 541 and 542—Table 16) which will not take a lethal dose. Repeat experiments at this strength indicate that an improvement in kill cannot be expected when red squill is repeatedly offered to these rats. Under cage conditions, and using good quality red squill powder (Sample A), a poison intake of not more than twice the M.L.D. can be expected. With the weaker strengths the poison intake is seldom sufficient to induce the symptoms of red squill poisoning—viz., tremors and sensory depression in the hind legs and excessive urination.

Munch, Silver and Horn (1929) reported on the extraction of the toxic principle of red squill with water, alcohol, acetone, and chloroform. Their conclusions were that the toxic principle is soluble in alcohol but not in water, acetone or chloroform, and "it seems evident that the cost of undertaking this on a commercial scale would far outweigh any possible benefit of marketing a more toxic preparation." Buck and Fellers (1935), using methyl and ethyl alcohols as solvents, extracted the toxic principle with Soxhlet apparatus, by stirring,

Table 16.

SHOWING TEST RESULTS WITH POWDERED RED SQUILL IN PREPARED FOOD.

Rat No.*	Poison Strength.	Poisoned Food. Intake. g.	Poisoned Food. Standard Intake. g./g.	Poison. Intake. mg.	Poison. Standard Intake. mg./kg.	Date Food Offered.	Date of Death.†	Weight (g.), and Sex of Rat (*R. conatus*).	Remarks.
129	1 : 50	3·87	·035	75·9	690·0	Aug. 10	Aug. 12	110 ; F.	Very sick on 11th.
130	1 : 50	6·13	·057	120·2	1,123·4	Aug. 10	Aug. 11	107 ; F.	
131	1 : 50	4·15	·037	81·4	733·4	Aug. 10	Aug. 11	111 ; F.	
132	1 : 50	3·49	·037	68·4	727·7	Aug. 10	Aug. 11	94 ; M.	
203	1 : 50	2·55	·030	50·0	591·8	Aug. 26	Aug. 28	84½ ; F.	Very sick on 27th.
237	1 : 50	1·78	·021	34·9	405·9	Sept. 2	..	86 ; F.	
238	1 : 50	5·38	·034	105·5	659·4	Sept. 2	Sept. 4	160 ; M.	Very sick on 3rd.
467	1 in 10	5·64	·057	564·0	5,697·0	Nov. 11	Nov. 12	99 ; F.	
468	1 in 10	1·47	·011	147·0	1,122·2	Nov. 11	Nov. 12	131 ; M.	} Died at 1 p.m.
469	1 in 10	1·41	·014	141·0	1,382·4	Nov. 11	Nov. 12	102 ; M.	
470	1 in 10	0·14	·001	14·0	133·3	Nov. 11	..	105 ; M.	
471	1 in 10	0·03	·0004	3·0	36·6	Nov. 11	..	82 ; F.	
472	1 in 10	0·76	·006	76·0	623·0	Nov. 11	Nov. 12	122 ; M.	
537	1 in 10	0·32	·002	32·0	222·3	Nov. 26	Nov. 27	144 ; M.	Weight 129 g. on 27th.
538	1 in 10	0·75	·010	75·0	1,042·0	Nov. 26	Nov. 27	72 ; F.	Weight 66 g. on 27th.
539	1 in 10	0·43	·004	43·0	361·4	Nov. 26	Nov. 27	119 ; M.	Weight 106 g. on 27th.
540	1 in 10	0·47	·004	47·0	443·4	Nov. 26	Nov. 27	106 ; M.	Weight 97½ g. on 27th.
541	1 in 10	0·24	·003	24·0	272·8	Nov. 26	..	88 ; F.	
542	1 in 10	0·19	·002	19·0	219·7	Nov. 26	..	86½ ; F.	
R 7	1 : 75	1·28	·011	16·8	138·9	June 22	..	121 ; M.	
R 7A	1 : 75	3·89	·032	51·2	432·4	June 28	..	..	
R 7B	1 : 75	3·32	·028	43·7	361·4	July 2	..	..	
R 7C	1 : 75	1·16	·009	15·1	124·9	July 7	..	..	
R 7D	1 : 75	2·39	·020	31·4	259·6	July 27	..	..	
R 7F	1 : 75	1·39	·012	18·3	151·3	Aug. 2	..	..	R 7E—sublethal dose of As_2O_3.
R 7G	1 : 75	1·49	·012	19·6	162·1	Aug. 5	..	..	
R 7H	1 : 75	3·26	·027	42·9	354·8	Aug. 10	..	..	Still healthy 1 month later.
R 8	1 : 75	1·66	·016	21·9	210·6	June 22	..	104 ; M.	
R 8A	1 : 75	1·15	·011	15·1	145·2	June 28	..	..	
R 8B	1 : 75	3·80	·037	50·0	480·8	July 2	..	..	
R 8C	1 : 75	2·96	·028	38·9	374·1	July 7	..	..	
R 8D	1 : 75	2·14	·021	28·2	271·2	July 27	..	..	
R 8E	1 : 75	1·24	·012	16·3	156·7	Aug. 2	..	..	
R 8F	1 : 75	3·45	·033	45·4	436·6	Aug. 5	..	..	
R 8G	1 : 75	4·50	·043	59·3	570·2	Aug. 10	..	..	Still healthy 1 month later.
R 11	1 : 75	2·27	·020	29·9	257·7	June 22	..	116 ; M.	
R 11A	1 : 75	2·79	·024	36·7	316·4	July 2	..	..	
R 11B	1 : 75	3·45	·030	45·4	391·3	July 7	July 8	..	Weight 88½ g. on 8th.
R 20F	1 : 75	3·95	·022	52·0	287·0	Aug. 5	..	181 ; M.	R 20A-E–sublethal doses of thallous sulphate.
R 20G	1 : 75	4·49	·025	59·1	326·2	Aug. 10	..	..	
R 20H	1 : 50	1·13	·006	22·2	122·5	Aug. 20	..	..	
R 20J	1 : 50	3·14	·017	61·6	340·0	Aug. 23	..	..	
R 75B	1 : 75	3·04	·029	40·0	392·4	Aug. 2	..	102 ; M.	
R 75C	1 : 75	4·72	·046	62·1	609·2	Aug. 5	..	..	
R 75D	1 : 75	3·74	·037	49·2	482·7	Aug. 10	..	..	Died from result of accident, Aug. 24th.

* R before rat number denotes that the specimen will be, or is being, returned for further test. Letter after rat number denotes the return : A for first, B for second, and so on.

† All rats not reported dead were used at later dates for other purposes.

and by a percolation method. These authors considered that "the advantages of red squill extract over red squill powder are that extract baits are more palatable and can be readily standardised as to toxicity, and rats will eat

the baits repeatedly." Both Munch *et al.* (1929) and Buck and Fellers (1935) dried the extracts, the latter on bran.

The author obtained extract of red squill in alcohol by using a Soxhlet apparatus over a five-hour extraction period. In expressing the poison strength of extract on food the weight of squill powder used to prepare the volume of extract dried on the food is given. For example, in Table 17 a poison strength of 1:10 indicates that, from an extract (stock solution) prepared with 150 ml. of industrial alcohol and 22·5 g. of Sample A red squill powder, 6·7 ml. of extract have been mixed with and dried on 10 g. of prepared food. In preparing weaker poison strengths alcohol was used to dilute the stock solution. This allows a direct comparison of the toxicity of the extract and the squill powder from which it was prepared. In Table 17 are set out the mean standard intakes for varying poison strengths.

Table 17.

SHOWING MEAN STANDARD INTAKE OF ALCOHOL EXTRACT OF RED SQUILL.

Poison Strength.	Mean Standard. Intake g./g.
1 : 10	·0065 ± ·0015
1 : 20	·010 ± ·0003
1 : 50	·028 ± ·002
1 : 93	·043 ± ·0035
1 : 140	·043 ± ·003
1 : 280	·046 ± ·0005
1 : 560	·051 ± ·004

At a poison strength of 1:280 the M.L.D. is 100 ± 20 mg./kg., and at 1:20 there is no appreciable change in this figure. At 1:10 it is not practicable to establish an M.L.D. direct by using feeding levels as defined by the author. At this strength (the most suitable for control work with the particular powder used) the mean standard intake is approximately six times the probable M.L.D.; intakes are regular when compared with those of poisoned food containing squill powder, and the kill obtained in cages is 100 per cent. The extract may also be used for snap baiting. However, it is necessary to soak the bread in the poison: this is a wasteful method and does not recommend the extract as suitable for snap baiting on a large scale. When using weaker poison strengths, intake following ingestion of sub-lethal doses may be satisfactory.

Satisfactory extracts were also made with powders B and C and industrial alcohol, and with all powders and methylated spirits. All powder residues were tested by drying out and mixing with prepared food in the proportion of 1:5. Standard intakes were irregular and the M.L.D.'s were 6,000 + mg./kg.

Claremont (1922) reported that the toxic principle from red squill could be extracted with hot water and with cold water. Munch *et al.* (1929) found that the exhaustion of red squill on a steam bath or in a Soxhlet thimble at 100 deg. C. caused almost total removal of the toxic principle. The author soaked Sample A powder in water over varying times and with periodic stirring. Table 18 contains test results of two small series using the aqueous extract from 15 g. of powder in 50 ml. of water for 48 hours. The extract was dried on prepared food in the proportions of 2·5 ml. and 1·5 ml. to 10 g. of food—*i.e.*, the poison strengths referred to the original powders are 1 : 13·3 and 1 : 22·2. Residue tests indicate that the exhaustion was partial only.

Table 18.

Showing Test Results with Aqueous Extract of Red Squill in Prepared Food.

Rat No.	Poison Strength.	Poisoned Food.		Poison.		Date Food Offered. (Prepared Oct. 11.)	Date of Death.	Weight (g.), and Sex of Rat (*R. conatus*).	Remarks.
		Intake. g.	Standard Intake. g./g.	Intake. g.	Standard Intake. mg./kg.				
40/505	1 : 13·33	1·55	·015	108·2	1,060·5	Nov. 26	Nov. 28	102 ; M.	All sick on 27th.
40/506	1 : 13·33	2·37	·025	164·0	1,744·7	Nov. 26	Nov. 28	94 ; M.	
40/507	1 : 13·33	3·67	·037	256·1	2,585·9	Nov. 26	Nov. 28	99 ; M.	
40/508	1 : 13·33	3·24	·036	226·1	2,539·4	Nov. 26	Nov. 28	89 ; M.	
40/509	1 : 13·33	2·90	·029	202·4	2,044·5	Nov. 26	Nov. 27	99 ; M.	
40/510	1 : 13·33	1·36	·015	94·9	1,031·6	Nov. 26	Nov. 27	92 ; F.	
40/511	1 : 22·22	1·04	·014	44·8	581·8	Dec. 11	..	77 ; F.	
40/512	1 : 22·22	2·08	·020	89·6	878·5	Dec. 11	..	102 ; M.	Slightly sick on 12th.
40/513	1 : 22·22	2·28	·017	98·2	711·6	Dec. 11	..	138 ; M.	
40/514	1 : 22·22	1·14	·006	49·1	265·4	Dec. 11	..	185 ; M.	Too old for standard testing.
40/515	1 : 22·22	1·85	·014	79·2	582·4	Dec. 11	..	136 ; M.	
40/516	1 : 22·22	2·23	·020	96·1	850·5	Dec. 11	..	113 ; M.	Slightly sick on 12th.

In Queensland there is no law requiring red squill containers to be labelled with the toxicity of the contents in terms of a standardized bio-assay. This, or some covering arrangement, would be necessary before a poison, with unknown chemical constitution and of such variable toxic content, could be considered for use in large-scale field applications, such as in Queensland canefields.

Strychnine.

Munch and Silver (1931), working with *R. norvegicus*, found that 20-25 mg./kg. killed practically all test animals within a period of five days. Considerable cage work with strychnine and rats has been reported from Hawaii by Pemberton (1925), Barnum (1930) and Borden (1942). These authors pointed out the irregular behaviour of strychnine as a rat poison. Burnett (1932), using the Wyoming ground squirrel *Citellus elegans elegans* as a test animal, found that "the amount of poisoned grain necessary to kill varies so much with individual squirrels that we are unable to decide what should be considered a lethal dose." Wright (1936) stated that rodents are much less susceptible to the action of strychnine than are the carnivora. Gard (1935), using strychnine hydrochloride and strychnine alkaloid at various poison strengths, killed respectively 64 per cent. and 60 per cent. of *R. conatus* in cages. This author considered a poison strength of 1 : 160 as suitable for strychnine on wheat.

In the author's experiments strychnine alkaloid, strychnine sulphate, and strychnine hydrochloride were used with prepared food. As no advantage was gained by using the salts they were discarded at an early date. Table 19 gives mean standard intakes of strychnine alkaloid poisoned food at different poison strengths.

Table 19.

SHOWING MEAN STANDARD INTAKES OF STRYCHNINE.

Poison Strength.	Mean Standard Intake g./g.
1 : 150 to 1 : 225	·018 ± ·002
1 : 500	·022 ± ·002
1 : 1,000	·027 ± ·005

Table 20 is a random selection of test results with strychnine in prepared food. Similar results were obtained when using this poison on wheat in the formula given by Lantz (1918) and adopted by Barnum (1930) against rats.

Deaths, mostly of young animals, may be caused by a strychnine intake as small as 8 mg./kg. On the other hand, a poison intake of 105 mg./kg. at a poison strength of 1:200 may not kill, and any change from a poison strength approximating closely to 1:200 does not improve efficiency. Wright (1936) stated that "the chief action (of strychnine) is upon the spinal cord" and the effect of the poison is "characterised by the sudden onset of a tetanic convulsion." He stated also that "the action of strychnine is rather remarkable, in that it is the symptoms which it provokes, rather than a direct toxic action, which are responsible for death." With strychnine poisoning the animal falls on a side and the whole body becomes rigid with the limbs and spine fully extended. The animal after death remains in this position. When clearing test cages during the morning, some rats were found with limbs extended and apparently dead. By afternoon, some of these recovered and seemed normal. Immediate repeat tests resulted in further poison intakes and effects which cannot be correlated with original intakes or previous individual reactions to the poison. There is no evidence that the regular administration of sub-lethal doses of strychnine has an accumulative effect. Furthermore, the intermittent ingestion of varying doses does not indicate that any tolerance exhibited is acquired by previous experience with the poison. In the cage experiments, the immunity to strychnine exhibited by a proportion of the test population was due to intake. Those rats requiring large lethal doses could not be given, by feeding methods at a single test period, a sufficient amount of poison to cause death. As well as the varying effects of strychnine on individuals within a species, there is an additional variation between species. The mean standard intake of strychnine poisoned food by *Melomys littoralis* is considerably higher than that by *Rattus conatus*. At a poison strength of 1:200 the food intake of *M. littoralis* is depressed by only approximately 50 per cent., but the relatively high intake does not proportionately increase the efficiency of the poison. Deaths occur after poison intakes between 30 mg./kg. and 380 mg./kg. and usually those killed have ingested considerable amounts of strychnine.

Variable and generally poor results can be expected from the use of strychnine as a rat poison in Queensland canefields.

Table 20.

SHOWING TEST RESULTS WITH STRYCHNINE ALKALOID IN PREPARED FOOD.

Rat No.	Poison Strength.	Poisoned Food.		Poison.		Date Food Offered.	Date of Death.	Weight (g.), Species, and Sex of Rat.	Remarks.
		Intake. g.	Standard Intake. g./g.	Intake. g.	Standard Intake. mg./kg.				
156	1 : 1,000	2·13	·024	2·13	23·5	Aug. 17	..	90½ ; *conatus* ; M.	Weight 80½ g. on 18th ; convulsions.
157	1 : 1,000	1·42	·016	1·42	16·0	Aug. 17	..	89 ; *conatus* ; F.	Weight 61 g. on 18th.
158	1 : 1,000	2·71	·023	2·71	23·2	Aug. 17	..	117 ; *conatus* ; F.	Weight 93 g. on 18th.
159	1 : 1,000	4·06	·034	4·06	33·8	Aug. 17	..	120 ; *conatus* ; M.	Weight 110½ g. on 18th.
160	1 : 1,000	7·74	·074	7·47	74·0	Aug. 17	..	101 ; *conatus* ; F.	Weight 94 g. on 18th.
161	1 : 1,000	4·03	·035	4·03	35·4	Aug. 17	..	114 ; *conatus* ; M.	Weight 101 g. on 18th.
162	1 : 1,000	1·58	·014	1·58	14·0	Aug. 17	Aug. 18	113 ; *conatus* ; M.	Weight 107 g. on 18th.
163	1 : 1,000	2·06	·017	2·06	16·9	Aug. 17	..	122 ; *conatus* ; F.	Weight 111 g. on 18th.
165	1 : 1,000	1·80	·016	1·80	16·1	Aug. 17	..	112 ; *conatus* ; M.	Weight 105 g. on 18th.
166	1 : 1,000	3·55	·030	3·55	30·1	Aug. 17	..	118 ; *conatus* ; M.	Weight 113 g. on 18th.
230	1 : 225	0·16	·002	0·70	8·5	Sept. 2	Sept. 3	83 ; *conatus* ; F.	
232	1 : 225	0·13	·002	0·60	7·9	Sept. 2	Sept. 3	76 ; *conatus* ; F.	
234	1 : 225	3·68	·027	16·40	120·6	Sept. 2	Sept. 3	136 ; *conatus* ; M.	
235	1 : 225	1·01	·009	4·50	40·9	Sept. 2	..	110 ; *conatus* ; F.	
237	1 : 225	0·78	·009	3·50	40·7	Sept. 2	..	86 ; *conatus* ; F.	
168	1 : 1,000	1·30	·028	1·30	28·3	Aug. 17	Aug. 18	46 ; *M. littoralis* ; M.	
169	1 : 1,000	4·70	·147	4·70	146·9	Aug. 17	..	32 ; *M. littoralis* ; F.	
170	1 : 1,000	3·31	·114	3·31	114·14	Aug. 20	..	29 ; *M. littoralis* ; F.	
201	1 : 225	3·89	·084	17·29	426·9	Aug. 26	Aug. 27	40½ ; *M. littoralis* ; M.	
231	1 : 225	2·43	·071	10·8	317·7	Sept. 3	Sept. 4	34 ; *M. littoralis* ; F.	

Thallous Sulphate.

Munch and Silver (1931) reviewed all available relevant literature on thallium and also presented results of feeding caged rats with thallium compounds. According to these authors there were very few reports on the action of thallium as a rodent poison prior to 1924 and their more important conclusions, based on literature and experiments, are—

1. The minimum lethal dose of thallous sulphate for wild rats or white rats is 31 mg./kg. with 10 to 20 per cent. error.

2. "Death usually occurs on the second or third day after feeding and is due to respiratory failure."

3. Thallium affects the autonomic nervous system, thereby producing alopecia (loss of hair) and internal disturbances.

4. Thallium is a cumulative poison of high toxicity and is without taste, smell, or other warning properties.

In 1929 Barnum (1930) introduced thallous sulphate into Hawaii and in cage tests found it very satisfactory. The poison was adopted in Javan field practice, Dilliwijn (1932) reporting that 3-5 mg. were sufficient to kill the Java field rat. Barnett (1935) stated that 4½ mg. of thallous sulphate would kill a rat (*R. conatus,* incorrectly called *R. culmorum,* and with an average adult weight of 125 g.).

Using B.D.H. thallous sulphate in varying proportions in prepared food, the mean standard intakes given in Table 21 were recorded. Similar intakes were recorded when wheat was substituted for prepared food. To prepare thallous sulphate treated wheat, a weighed quantity of thallous sulphate is

Table 21.

SHOWING MEAN STANDARD INTAKES OF THALLOUS SULPHATE.

Poison Strength.	Mean Standard Intake g./g.
1 : 3,000	·068 ± ·0045
1 : 1,000	·067 ± ·0055
1 : 500	·038 ± ·003
1 : 300	·037 ± ·003
1 : 250	·029 ± ·0017
1 : 100	·028 ± ·002
1 : 50	·027 ± ·002
1 : 25	·025 ± ·002

dissolved in the minimum volume of hot to boiling water; this is quickly poured over and stirred into the weighed wheat, which is then spread out to dry. The intakes of wheat treated in this manner are similar to those of poisoned wheat prepared by the modified thallium sulphate-wheat formula of Barnum (1930, p. 438). Furthermore, when samples prepared by each method are shaken vigorously for 20 minutes in tins, then screened and analysed, no significant loss of thallium is shown. On occasions commercial thallous sulphate treated wheat was used in tests. The poison strength of these bulk preparations was invariably lower than that claimed on the label: *e.g.,* samples from containers labelled 2 lb. of thallous sulphate to 2,000 lb. of wheat on chemical analysis showed poison strengths from 1:1,100 to 1:1,200. In all test calculations with these materials poison strengths based on chemical analyses were used.

For all poison strengths the M.L.D. of thallous sulphate is 30 ± 3 mg./kg. It is a very reliable poison and only occasionally does a rat, usually a large and virile male (see rat No. R20F, Table 22) or a pregnant female, live after an intake of 50 mg./kg. The accumulative action of the poison depends on a time x dosage factor. Doses less than 20 mg./kg. given on successive nights over a six-day period will not kill. The animal can apparently eliminate from its system sufficient of the poison in a 24-hour period to keep alive. If one of the doses during any night exceeds 20 mg./kg. death usually occurs. With intermittent feeding an occasional poison intake approaching the lethal dose can be

Table 22.

SHOWING TEST RESULTS WITH THALLOUS SULPHATE IN PREPARED FOOD.

Rat No.*	Poison Strength.	Poisoned Food. Intake. g.	Poisoned Food. Standard Intake. g./g.	Poison. Intake. mg.	Poison. Standard Intake. mg./kg.	Date Food Offered.	Date of Death.	Weight (g.), and Sex of Rat (*R. conatus*).	Remarks.
R 13	1 : 3,000	6·66	·063	2·22	20·9	June 22	..	106 ; M.	
R 13A	1 : 3,000	4·83	·046	1·61	15·2	June 28	..	..	
R 13B	1 : 3,000	6·71	·063	2·24	21·1	July 2	..	..	
R 13C	1 : 2,000	6·90	·065	3·45	32·5	July 8	..	..	
R 13D	1 : 1,000	4·00	·038	4·00	37·7	July 13	..	..	
R 13E	1 : 1,000	1·20	·011	1·20	11·3	July 15	July 16	..	Weight 78 g. on 16th.
R 15	1 : 3,000	8·19	·065	2·73	21·7	June 22	..	126 ; M.	
R 15A	1 : 3,000	0·77	·006	0·26	2·1	June 28	..	..	
R 15B	1 : 3,000	1·10	·009	0·37	2·9	July 2	..	..	
R 15C	1 : 2,000	6·52	·052	3·26	25·9	July 3	..	..	
R 15D	1 : 1,000	4·40	·035	4·40	34·9	July 13	..	..	
R 15E	1 : 1,000	Nil	Nil	Nil	Nil	July 15	..	..	
R 15F	1 : 1,000	1·50	·012	1·50	11·9	July 19	July 21	..	Weight 91 g. on 21st.
R 17	1 : 3,000	12·48	·089	4·16	29·5	June 22	..	141 ; M.	
R 17A	1 : 3,000	5·89	·042	1·96	13·9	July 2	..	..	
R 17B	1 : 1,000	6·05	·043	6·05	42·9	July 8	..	..	
R 17C	1 : 1,000	6·45	·046	6·45	45·8	July 13	July 14	..	Weight 112½ g. on 14th.
R 18	1 : 3,000	8·10	·072	2·70	23·9	June 22	..	113 ; M.	
R 18A	1 : 3,000	6·90	·061	2·30	20·3	July 2	..	..	
R 20	1 : 3,000	6·72	·044	2·24	14·7	June 28	..	152 ; M.	
R 20A	1 : 2,000	7·68	·051	3·84	25·3	July 2	..	..	
R 20B	1 : 2,000	2·59	·017	1·30	8·5	July 7	..	..	
R 20C	1 : 1,000	5·15	·030	5·15	30·0	July 13	..	171½ ;	
R 20D	1 : 1,000	2·50	·015	2·50	14·6	July 15	..	..	
R 20E	1 : 500	3·27	·019	6·54	38·1	July 19	..	..	
R 20F	1 : 500	4·43	·025	8·86	50·6	July 27	..	175	*See* also Table 16.
R 37	1 : 1,000	8·61	·085	8·61	85·3	July 12	..	101 ; M.	
R 37A	1 : 1,000	5·64	·056	5·64	55·9	July 15	July 16	..	Weight 84½ g. on 16th.
R 38	1 : 1,000	10·30	·067	10·30	67·1	July 12	..	153½ ; F.	Gave birth to 5 young on 12th.
R 38A	1 : 1,000	4·60	·030	4·60	30·0	July 15	July 17	..	
R 39	1 : 1,000	12·07	·094	12·07	94·3	July 12	July 14	128 ; M.	
R 40	1 : 1,000	8·00	·086	8·00	86·0	July 12	..	93 ; M.	
R 40A	1 : 1,000	3·30	·036	3·30	35·5	July 15	July 20	..	Weight 65 g. on 20th.
R 41	1 : 1,000	6·30	·065	6·30	65·0	July 12	..	97 ; M.	
R 41A	1 : 1,000	2·80	·029	2·80	28·9	July 15	July 16	..	Weight 77½ g. on 16th.
R 43	1 : 1,000	9·80	·084	9·80	83·8	July 12	..	117 ; F.	
R 43A	1 : 1,000	Nil	Nil	Nil	Nil	July 15	July 16	..	Weight 100½ g. on 16th.
R 44	1 : 1,000	5·2	·036	5·20	35·6	July 12	..	146 ; F.	
R 44A	1 : 1,000	3·17	·021	3·17	21·0	July 15	July 17	..	Weight 109 g. on 17th.
48	1 : 1,000	9·22	·096	9·22	96·0	July 19	July 23	96 ; M.	
49	1 : 1,000	5·67	·079	5·67	78·7	July 19	July 23	72 ; M.	Young for test.
50	1 : 1,000	5·78	·065	5·78	64·6	July 19	July 23	89½ ; M.	
51	1 : 1,000	5·20	·063	5·20	63·1	July 19	July 23	82½ ; M.	Young for test.
52	1 : 1,000	7·25	·057	7·25	56·9	July 19	July 23	127½ ; M.	
53	1 : 1,000	6·85	·050	6·85	50·4	July 19	July 22	136 ; M.	
2	1 : 300	4·72	·031	15·7	101·6	June 14	June 20	154½ ; M.	
3	1 : 300	5·62	·036	18·7	121·1	June 14	June 17	154½ ; M.	
4	1 : 300	4·12	·040	13·7	133·0	June 14	June 16	103 ; M.	
5	1 : 300	3·55	·024	11·8	80·8	June 14	June 18	146 ; M.	
6	1 : 300	5·84	·035	19·5	115·4	June 14	June 17	169 ; M.	
804	1 : 50	7·52	·031	147·5	602·0	Sept. 19	Sept. 21	245 ; M.	
805	1 : 50	1·38	·017	27·1	334·6	Sept. 19	Sept. 21	81 ; M.	Young for test.
806	1 : 50	2·82	·024	55·3	462·1	Sept. 19	Sept. 21	118 ; M.	
808	1 : 50	6·02	·032	118·0	638·0	Sept. 19	Sept. 21	185 ; M.	
809	1 : 50	2·16	·018	42·4	353·4	Sept. 19	Sept. 21	120 ; F.	
810	1 : 25	5·21	·033	200·4	1,268·4	Sept. 19	Sept. 20	158 ; M.	
811	1 : 25	2·65	·031	101·9	1,191·9	Sept. 19	Sept. 20	85½ ; M.	Young for test.
812	1 : 25	2·02	·028	77·0	1,069·5	Sept. 19	Sept. 20	72 ; M.	
813	1 : 25	3·30	·025	127·0	955·0	Sept. 19	Sept. 21	133 ; M.	
814	1 : 25	1·61	·016	62·0	608·0	Sept. 19	Sept. 21	102 ; M.	
815	1 : 25	3·01	·030	115·8	1,158·0	Sept. 19	Sept. 20	100 ; M.	

* R before rat number denotes that the specimen will be, or is being, returned for further test. Letter after rat number denotes the return : A for first, B for second, and so on.

eliminated by the animal. The sum of poison intakes on successive nights may be greater than the M.L.D. without death occurring (see Rat No. 18, Table 22). (A bandicoot, *Perameles nasuta,* weighing 1,216 g. ate 40 g. of 1:500 thallous sulphate-wheat on each of five successive nights; death occurred on the sixth night.)

Table 23.

SHOWING TEST RESULTS WITH THALLOUS SULPHATE, FED ON TWO CONSECUTIVE NIGHTS.*

Rat No.†	Poison Strength.	Poisoned Food.		Poison.		Date Food Offered	Date of Death.	Weight (g.), and Sex of Rat (*R. conatus*).	Remarks.
		Intake. g.	Standard Intake. g./g.	Intake. mg.	Standard Intake. mg./kg.				
R 644	1 : 500	4·43	·037	8·84	74·3	Feb. 3	..	119; M.	
R 645	1 : 500	6·28	·050	12·54	99·1	Feb. 3	..	126½; M.	
R 646	1 : 500	4·74	·046	9·46	91·0	Feb. 3	..	104; M.	
R 647	1 : 500	3·32	·037	6·63	74·1	Feb. 3	..	89½; F.	
R 648	1 : 500	5·61	·057	11·20	114·3	Feb. 3	..	98; F.	
R 649	1 : 500	4·50	·046	9·00	91·9	Feb. 3	..	98; M.	
R 650	1 : 500	4·50	·043	9·00	86·2	Feb. 3	..	104½; F.	
R 651	1 : 500	4·03	·050	8·05	99·4	Feb. 3	..	81; F.	
R 652	1 : 500	4·49	·045	8·96	89·2	Feb. 3	..	100½; M.	
R 644A	1 : 500	0·46	·004	0·92	7·7	Feb. 4	Feb. 6	..	
R 645A	1 : 500	4·72	·037	9·42	74·5	Feb. 4	Feb. 6	..	
R 646A	1 : 500	4·81	·046	9·60	92·4	Feb. 4	Feb. 6	..	
R 647A	1 : 500	0·70	·008	1·40	15·7	Feb. 4	Feb. 6	..	
R 648A	1 : 500	5·64	·058	11·26	115·0	Feb. 4	Feb. 5	..	
R 649A	1 : 500	5·37	·055	10·72	109·4	Feb. 4	Feb. 6	..	
R 650A	1 : 500	0·45	·004	0·90	8·6	Feb. 4	Feb. 6	..	
R 651A	1 : 500	0·61	·008	1·22	15·1	Feb. 4	Feb. 6	..	
R 652A	1 : 500	0·72	·007	1·44	14·3	Feb. 4	Feb. 6	..	
R 714	1 : 250	3·14	·032	12·5	126·3	Mar. 14	..	99; M.	
R 715	1 : 250	2·97	·029	11·8	115·2	Mar. 14	..	102½; M.	
R 716	1 : 250	2·39	·022	9·5	88·0	Mar. 14	..	108; M.	
R 717	1 : 250	4·57	·035	18·2	137·9	Mar. 14	..	132; M.	
R 718	1 : 250	3·69	·032	14·7	129·0	Mar. 14	..	114; M.	
R 719	1 : 250	2·90	·037	11·5	145·6	Mar. 14	..	79; M.	Too young for standard intake test.
R 714A	1 : 250	1·51	·015	6·0	60·6	Mar. 15	Mar. 17	..	
R 715A	1 : 250	1·20	·012	4·8	46·6	Mar. 15	Mar. 17	..	
R 716A	1 : 250	0·52	·005	2·1	19·5	Mar. 15	Mar. 17	..	
R 717A	1 : 250	0·99	·008	3·9	29·5	Mar. 15	Mar. 17	..	
R 718A	1 : 250	1·32	·012	5·3	46·5	Mar. 15	Mar. 17	..	
R 719A	1 : 250	0·41	·008	1·6	20·3	Mar. 15	Mar. 17	..	
R 744	1 : 100	4·19	·037	41·5	367·3	Mar. 22	..	113; M.	
R 745	1 : 100	2·30	·013	22·8	131·4	Mar. 22	..	173½; M.	Too old for standard intake test.
R 746	1 : 100	3·44	·030	34·1	294·0	Mar. 22	..	116; M.	
R 747	1 : 100	4·96	·035	49·1	350·7	Mar. 22	..	140; M.	
R 748	1 : 100	3·35	·030	33·2	297·8	Mar. 22	..	111½; M.	
R 749	1 : 100	3·23	·027	32·0	272·4	Mar. 22	..	117½; M.	
R 744A	1 : 100	Nil	..	..	..	Mar. 23	Mar. 25	..	Very sick on 24th.
R 745A	1 : 100	Nil	..	..	..	Mar. 23	Mar. 25	..	
R 746A	1 : 100	Nil	..	..	..	Mar. 23	Mar. 24	..	
R 747A	1 : 100	Nil	..	..	..	Mar. 23	Mar. 24	..	
R 748A	1 : 100	Nil	..	..	..	Mar. 23	Mar. 25	..	Very sick on 24th.
R 749A	1 : 100	Nil	..	..	..	Mar. 23	Mar. 24	..	

* Bait base was prepared food for poison strength of 1 : 500, and whole wheat for other strengths.

† R before rat number denotes that the specimen will be, or is being, returned for further test. Letter after rat number denotes the return : A for first.

Gross symptoms of thallous sulphate poisoning are general depression, loss of muscular control in the hind legs, and watery eyes. Unlike the symptoms of red squill and strychnine poisoning, once those of thallium are apparent

death is inevitable. The visible sign of continued sub-lethal dosing is alopecia. These gross symptoms usually become apparent closer to the time of death than to the time of ingestion of the lethal dose. Rats generally die on the third day following lethal ingestion, occasionally they die on the second day, and sometimes they live for five days after the intake of the lethal dose (see Tables 22 and 23). Between the ingestion of the lethal dose and the onset of gross symptoms rats may feed more or less in a normal manner: this phenomenon, exhibited to any extent only with thallium poisoning, is termed secondary feeding. With sub-lethal intakes and secondary feeding at a poison strength of 1:1,000 approximately 75 per cent. of poison intake is waste and is of little importance in increasing percentage kill in test cages. The elimination of wastage of poison without lessening kill, and the correlating of total poisoned food intake with efficiency, involve a consideration of both initial poison intake and the amount of secondary feeding. Table 23, in which are tabulated some results of tests on two consecutive nights, indicates that secondary feeding under cage conditions is eliminated when a poison strength of 1:100 is used; but the initial intake of poison is large. Cage experiments show that the most economical and efficient poison strength for thallous sulphate treated favoured food is between 1:500 and 1:100: a more specific strength for field use can be nominated only by field tests with known rat populations.

Thallous sulphate is an outstanding rat poison for use in food baits.

A proprietary paste, which by analysis contained 2·5 per cent. of thallium, and two prepared pastes containing 5 per cent. and 10 per cent. thallous sulphate, were used with bread and bran. Negligible takes were recorded and kill was poor. It is concluded that thallous sulphate in paste form is not suitable for use in snap baits.

Miscellaneous.

The oily liquid, glycerol monochlorhydrin, was found to be insufficiently toxic for use with whole grain.

Only preliminary experiments were undertaken using zinc phosphide. This chemical had not been used as a rat poison in Queensland canefields and it did not compare favourably with thallous sulphate.

Sulphurised linseed oil (R. B. Harvey), sulphur, naphthalene, creosote, and dieseline were tried as repellants by either spraying, painting, or dusting the materials on sugar cane supplied in inhabited living cages. All canes so treated were eaten, although some of the rats attacking the creosote-sprayed canes were poisoned.

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SEED-HARVESTING AND OTHER ANTS IN THE TOBACCO-GROWING DISTRICTS OF NORTH QUEENSLAND.

By J. HAROLD SMITH, M.Sc., Senior Research Officer, Division of Plant Industry (Research) and D. O. ATHERTON, M.Sc.Agr., Research Officer, Division of Plant Industry (Research).

SUMMARY.

1. An investigation was carried out into tobacco seed-bed failures caused by an indigenous ant fauna.

2. The funnel ant, Aphaenogaster longiceps, was a serious pest because of the ramifications of the nest and the soil disturbance associated with the formicary. The chief seed-harvesting species were Monomorium rothsteini var. leda, Pheidole impressiceps, P. variabilis, and Pheidolacanthinus mjobergi. The bionomics of these and of some other species are discussed.

3. Granary contents of nests belonging to granivorous ants reflect the seed-fall at a given period, the character of the flora, and the ability of the workers to carry the seed.

4. Species which do not harvest seed preponderate in the coarse white sands and seed-harvesting species in the river silts; brown sands contain numerous nests of both types. An explanation of the species distribution, based on the reaction of individual species to the physical characteristics of the soil and on an analysis of available food materials, is suggested.

5. Losses from seed-harvesting ants may be eliminated by establishing seed-beds some distance away from the nests of the more distinctive species, by destroying nests on the site before preparing the seed-bed, or by applying sand covers immediately after sowing the seed. The river sand retained on a 16-mesh sieve, when applied to a depth of one-eighth inch, gives adequate protection.

6. Baiting is sometimes necessary to prevent damage by ants which harvest the cotyledons from seedlings. These ants collect maize meal more readily than either tobacco seed or the cotyledons of seedlings, and broadcast applications of the meal at a rate of 12 oz. per 100 square feet on and near the seed-beds give effective control. The addition of a poison to the bait is not necessary, as nest destruction is of secondary importance.

INTRODUCTION.

During recent years a considerable area of land situated in the vicinity of the townships of Mareeba and Dimbulah, which lie in the Cairns hinterland of North Queensland, has been used for the cultivation of tobacco. The producing districts are watered by the Barron and Walsh Rivers and their tributaries, but as most of these streams flow only after heavy rains the water supply, except in a few comparatively small areas, is inadequate for field

irrigation, though sufficient for the watering of tobacco seed-beds. The underlying rock throughout the area is either granite or sandstone, and the derived soils are essentially of a sandy type. Three types are recognized, viz., river silts, brown sands, and white sands.

The annual rainfall of the district ranges from 20 inches to 30 inches, the greater part falling during the three summer months of January, February and March. Transplanting takes place on non-irrigated farms from the beginning of December to the end of January, so as to take advantage of the summer rainfall. In order to provide seedlings for transplanting during this period, seed-beds are planted at fortnightly or three-weekly intervals from mid-October onwards, though where field irrigation is practised seed-beds may be established much earlier. Any considerable interference with seedling development in the seed-beds may therefore disturb the whole planting programme.

When the tobacco-growing industry was first established in the Mareeba-Dimbulah area, serious seed-bed failures occurred. In some instances the seedlings were destroyed in the cotyledon stage, but more commonly seedlings did not appear above the ground and subsequent broadcast sowings yielded no plants. An examination of these seed-bed failures showed that most could be attributed to the depredations of seed-harvesting ants. Considerable damage was also caused by other species nesting in the seed-bed site. Many seed-beds had been established over the nests of these species, and mounds thrown up by the ants frequently smothered a large proportion of the seedlings. Runways used by foraging workers of some comparatively large species crossed and recrossed some seed-beds, causing damage.

A considerable number of ant species occur in the virgin soils of these tobacco-growing districts (see Appendix 2). Species which do not harvest seed attract most attention owing to their larger size, but a close examination of nest incidence indicates that granivorous forms are very common. Ant nests are so abundant in some soils that it is difficult to find a single square yard free from nest openings.

The trees of the Mareeba and Dimbulah soils, which are relatively infertile, are of the stunted, sclerophyllous type; but during the wet summer months there is an abundant ground flora in which grasses and legumes are common. Most of these herbaceous plants are ephemerals which shed their seed in autumn and early winter, thus providing sufficient food to support a large population of seed-harvesting ants.

ANTS ASSOCIATED WITH TOBACCO SEED-BEDS.

The ants associated with tobacco seed-beds and their surroundings may be grouped into three classes, viz.—(*a*), species which are apparently innocuous; (*b*), species which disturb the surface of prepared seed-beds; and, (*c*), species which harvest either the seeds or cotyledons or both.

The more important species in the several classes are discussed hereunder. The description given in each case is intended merely to indicate the main features which the field agronomist working in the tobacco-growing districts of North Queensland may use to distinguish the various species.

Apparently Innocuous Species.

Apparently innocuous species of ants comprise forms which, though collected in or near seed-bed areas, have no harmful effect on the growth of the seedlings. They do not harvest seed or cotyledons and seldom disturb the surface of the seed-bed.

Crematogaster (Acrocoelia) fusca Mayr.

Of the several species of *Crematogaster* which are found in and about tobacco seed-beds, *C. fusca* is the largest. The workers are between 3mm. and 4mm. long and, except for the lighter coloured appendages, are shining black in colour. The meso-thorax and metanotum are minutely rugose, but elsewhere the integument is smooth. The metanotum bears two short, stout spines on the posterior dorsal edge, and fine, short hairs are scattered over the whole of the body.

Nests of this species are established in trees or logs and are generally situated beneath loose bark or in calloused tissues on the stem and branches. Several colonies have been observed on tea trees (*Melaleuca* spp.) growing in the beds of streams which are occasionally flooded. Nests on separate trees may be connected by runways on the ground.

The workers, besides garnering pieces of plant debris, dead insects and other organic materials, often carry white fragments of quartz into the nest. They occasionally fight the larger mound ant, *Iridomyrmex detectus* Sm. s.sp. *sanguinea* For., which is repelled by a poisonous fluid ejected through the tip of the heart-shaped gaster.

Crematogaster pallipes Mayr.

The workers of *C. pallipes* are between 2mm. and 2·5mm. in length and are brown in colour, with the gaster grading into a darker shade towards the posterior. The thorax and pedicel are minutely punctate and there are two sharp spines on the metanotum. The remainder of the integument is smooth, but the whole of the body is covered with long, scattered hairs.

The nests of this species occur in the ground, the brood chambers and galleries being approached through an arc-shaped passageway, which is just beneath the surface for most of its length, but which invariably breaks through the ground several times, especially under fallen leaves and twigs. The species is common in seed-bed areas of the Mareeba district. Both this insect and *C. fusca* are widely distributed throughout Australia (Tillyard, 1926).

Crematogaster pythia For.

The workers of *C. pythia* are 2·5mm. to 3mm. in length and are light brownish-yellow in colour except for the posterior abdominal segments, which are dark-brown. Fine, short hairs are scattered over the body; the thorax and pedicel are minutely punctate, and the integument of the head and gaster is smooth. The nest is similar to that of *C. pallipes.*

Paratrechina (Nylanderia) obscura Mayr.

The workers of *P. obscura* are about 3mm. long and are black in colour, though the antennae and tarsi are light-brown. The integument is smooth and shining and, except for the metanotum, carries numerous stout hairs or bristles.

The underground nests of this ant are usually entered through a single opening, which is often situated under a tussock of grass and surrounded by a characteristic mound. There is a comparatively large chamber immediately under the nest opening, and from this the galleries lead into the nest. Several nests are often linked together by runways. *P. obscura* has a fairly extensive foraging range and nests have been located in river beds which are frequently inundated during the summer. The species is widely distributed in the drier parts of the district.

Other apparently innocuous species which have been collected in seed-bed areas are *Tapinoma minutum* Mayr. var. *integrum* For., *Opisthopsis haddoni* Emery, *Opisthopsis pictus* Emery var. *lepidus* Wheeler, *Polyrachis (Chariomyrma) aurea* Mayr., and *Camponotus (Tanaemyrmex) novaehollandiae* Mayr.

Ants Disturbing the Surface of Seed-Beds.

A number of ants sometimes disturb the surface of the seed-bed by throwing up mounds of earth during nest construction or by establishing runways on the site. The excavated earth smothers the seedlings, while plants on or near the runways are destroyed.

Aphaenogaster (Nystalomyrma) longiceps For.—**The Funnel Ant.** (Plate 1.)

The funnel ant is probably the most conspicuous ant pest of tobacco seed-beds in North Queensland. The workers are between 5mm. and 6mm. in length and are uniformly chestnut-brown in colour. The body is clothed with hairs, which are sparsely distributed over the smooth integument, and there are two metanotal spines.

Funnel ants sometimes nest in areas which are otherwise suitable for the production of seedlings. Colonies may cover several square chains and possess several openings to each square yard of surface. Each of the more or less vertical openings of the nest is surrounded by a crater of loose earth about six inches in diameter: hence the common name of funnel ant. The opening varies a great deal in size, but is usually about one-half inch across. The openings may be so numerous that the loose earth of the craters covers most of the intervening ground. The funnels lead to the brood chambers and galleries underground. When seed-beds are constructed in badly-infested areas, the effect on the seedlings is serious. The small plants are buried under the freshly excavated material, and sometimes very poor stands may be attributed solely to the nesting operations of the funnel ant. The activity of the workers is not greatly affected by temperature, though foraging operations are most

pronounced in the late afternoon. Funnel ants have not been observed harvesting seed. In the tropical red loams of the adjacent Atherton Tableland they may attend aphids (*Geoica* sp.) on the roots of grasses. This ant is widespread in North Queensland and is common in both the Mareeba and the Dimbulah districts.

Fig. 1.

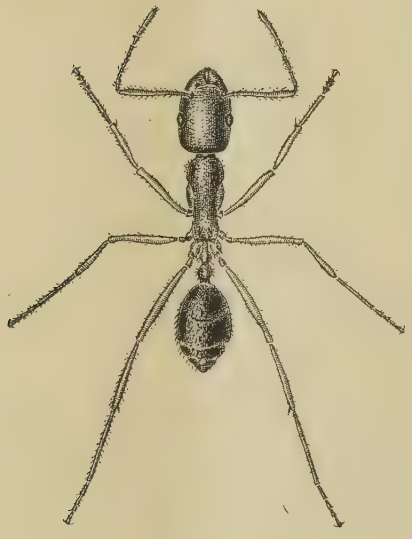

Fig. 2.

Plate 1.

Aphaenogaster (*Nystalomyrma*) *longiceps* Sm.—Fig. 1. Winged female × 4; fig. 2. Worker × 7.

[*Drawings by William Manley.*

Iridomyrmex detectus Sm., s.sp. ***sanguinea*** For.—**The Mound Ant.**

The mound ant is one of the larger seed-bed species and is perhaps the best known insect in Australia (Tillyard, 1926). The workers are about 6mm. long, with red-coloured head and thorax. The gaster and legs, except for the tarsi, are plum-coloured. Both legs and antennae are long and slender. There are a few scattered hairs on the integument of the head, thorax and abdomen. The winged females are comparatively large—12mm. in length—and their colour pattern differs little from that of the workers. The mesothorax is, however, plum-coloured and not red as in the worker.

The formicaries of this species are characteristically bare of vegetation and are decidedly mound-like, though the mound may not be more than one foot high. The mound is pierced by several openings about 6mm. to 8mm. in diameter, which lead to the extensive underground galleries of the nest. There are always a number of well-defined pathways, varying in width from three inches to six inches, leading away from the mound. These may be traced for several chains from the nest, and they frequently connect adjacent mounds.

Mound ants are continually at war with the numerous mound-erecting termites and they frequently inhabit termitaria from which the original occupants have been ousted. Sometimes a termitarium is occupied simultaneously by a colony of termites and by mound ants, the termites having preserved part of the colony intact by constructing walls to prevent further ingress by the predatory species.

The workers are extremely rapacious and attack any dead or disabled animal in the vicinity of the mound. Other insects are attacked. Mound ants are also partial to sweet substances and frequently invade houses or camps.

Should tobacco seed-beds cut across a previously-used runway, the ants may re-establish the track after the seed has been sown. Shade conditions under the seed-bed covers may also attract the workers and runways frequently deviate from an old track to pass along the seed-bed. Seedlings on these runways are inevitably destroyed and the losses occasionally reach serious proportions. The mound ant is present in all tobacco-growing regions of the State.

Iridomyrmex rufoniger Lowne.
Iridomyrmex rufoniger Lowne s.sp. ***pallidus*** For.

As *I. rufoniger* and its sub-species *pallidus* are closely related and as their habits are very similar, they can conveniently be discussed together. Differences in the colour of the integument of *I. rufoniger* and the sub-species are very striking, for while *I. rufoniger* is dull-brown to black in colour, its sub-species is uniformly light chestnut-brown. The workers are 3·5mm. in length, and have long, slender legs and antennae; the coxae are large and robust. The integument of the whole insect is smooth and possesses a uniform covering of very fine, short hairs.

In the underground nests there are numerous more or less closely-spaced chambers at a depth of one or two feet. Access to the nest is provided by one or more entrance holes, each of which is about 5mm. across and surrounded

by a symmetrical crater-shaped earth mound. Formicaries of *I. rufoniger* usually contain a greater number of individuals than do those of the sub-species *pallidus*. The latter is generally the less active, though both are very quick in their movements compared with other ants. The workers appear at dawn in summer but are almost inactive during the hotter hours of the day. In the late afternoon the insect is again actively foraging for food.

The earth crater surrounding the entrance holes may be formed in tobacco seed-beds during the reconstruction of an old nest after seed-bed preparations have been completed. When these craters occur in seed-beds, some seedlings are destroyed. The losses may be due either to the inhibition of germination by the crater-mound or to the smothering of seedlings after the plants have appeared above the ground. *I. rufoniger* is more troublesome than its sub-species, but losses are never considerable.

Both insects are widely distributed throughout the tobacco-growing districts of North Queensland and probably occur on most tobacco farms.

Seed-Harvesting Ants.

The discussion of seed-harvesting ants is complicated by the multiplicity of species involved. Four genera—*Pheidole, Pheidolacanthinus, Monomorium,* and *Meranoplus*—contain injurious species. The importance of individual species frequently varies from farm to farm, but some are represented in the ant fauna of almost all seed-beds.

Relatively large seed-harvesting species, such as *Monomorium rothsteini* var. *leda,* have a considerable foraging range but the nests are usually far apart. Consequently, seed-beds are often established in potentially dangerous areas without any seedling losses ensuing, germination having been completed before the seed has been discovered by the workers. If, however, the seed-beds are established close to, or over, nests of this species, losses are certain to occur unless special precautions are taken to protect the seed.

Though the depredations of the larger seed-harvesting species may sometimes be avoided by the chance disposition of the seed-beds, there is little prospect of ever escaping the attentions of the smaller ants whose nests crowd river silt soils. Practically any seed-bed site selected on these soils will contain nests of the smaller seed-harvesting species and some of the seed at least will be taken by foraging workers before germination. If sowing rates are heavy, the unharvested residue on the seed-beds may be sufficient to give a satisfactory strike of plants. Ants, however, remove the seed indiscriminately and, where they have been active, parts of the seed-bed carry few, if any, seedlings.

If the presence of ant nests on seed-bed sites has not been noticed during the preparation of the seed-beds, it soon becomes apparent when the workers renew the nest openings destroyed during cultivation. Within a day or two from sowing the tobacco seed, crater-like mounds, the size of which depends on the species of ant, appear in the seed-beds and the workers resume

foraging operations. Seed in the immediate vicinity of the nest opening first attracts attention and the workers show little inclination to search further afield for provender. It is thus not surprising that successive sowings on seed-beds, where ants are active, are invariably failures unless special precautions are taken to cope with the pest.

The seed-harvesting species of economic importance generally confine their attention to tobacco seed and, although a number may nip off fragments from the cotyledons, all, except *Pheidolacanthinus mjobergi*, can for all practical purposes be treated as essentially seed-harvesting forms. The partiality of *P. mjobergi* for cotyledons as well as for the ungerminated seed sometimes necessitates the adoption of special control measures.

Of the species to be discussed, two—*Monomorium rothsteini* var. *leda* and *Pheidolacanthinus mjobergi*—are relatively large in size and inhabit nests with very large populations. Both may be very destructive. In each case, however, the recorded losses are sporadic and it is doubtful whether their importance to the industry equals that of *Pheidole impressiceps* Mayr. and *P. variabilis* Mayr., whose nests occur in nearly all seed-beds.

In the following discussion, the several seed-harvesting species are treated in the order of their generic affinities.

Monomorium (Monomorium) rothsteini For. var. ***leda*** For. (Plate 2.)

One of the larger seed-harvesting ants frequenting tobacco seed-beds is *Monomorium rothsteini* var. *leda;* its thickly-populated runways leading to the nests are a striking feature of many tobacco soils. The workers are very active and may forage a considerable distance from the nest: losses are frequently due to the inhabitants of nests situated more than one chain from the seed-beds.

The workers are 4mm. to 4·5mm. in length. The head, thorax and pedicel are reddish-brown in colour but the gaster and the scales of the pedicel segments are dark-brown or almost black, the intensity of these colours depending largely on the age of the individual. The whole of the thorax, other than the dorsum of the prothorax, is finely reticulate, and the posterior receding slope of the metanotum carries a number of transverse ridges. The femora are much darker than the other segments of the legs and thorax.

Alate forms are large—8mm. to 10mm. in length—and have been recovered from nests examined during the summer months. In the male, the head, thorax and pedicel are jet black while the gaster and appendages are reddish-brown. In the female, the head is reddish, the thorax smooth glossy black, and the whole of the abdomen fuscous.

The external appearance of the nest varies a great deal. At times, extruded debris may be deposited some distance from the external opening and when such heaps are levelled during the natural process of weathering the nest site becomes somewhat raised and may cover an area of more than one square yard. Occasionally the mound is restricted to the nest opening.

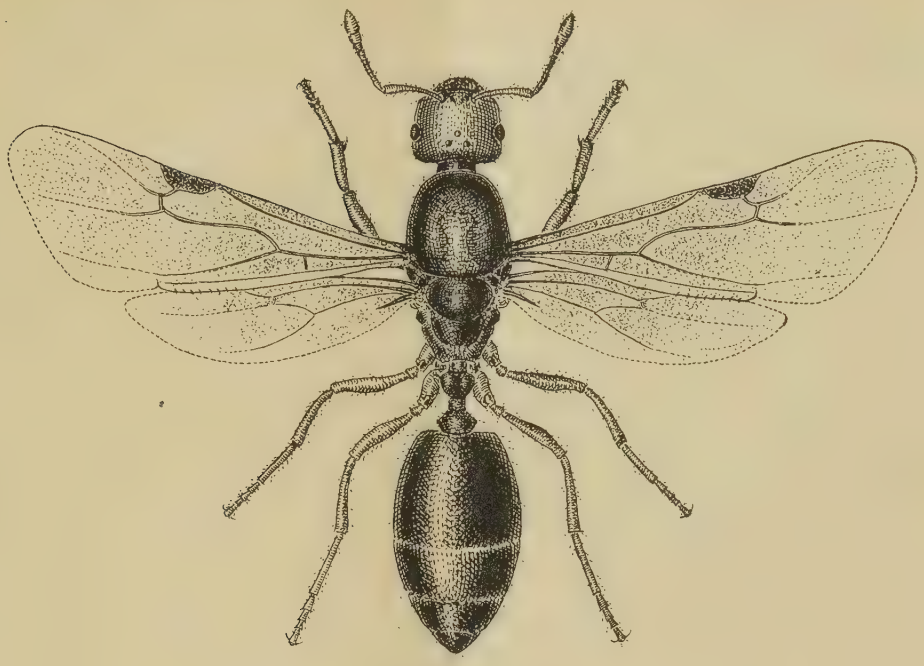

Fig. 1.

Fig. 2.

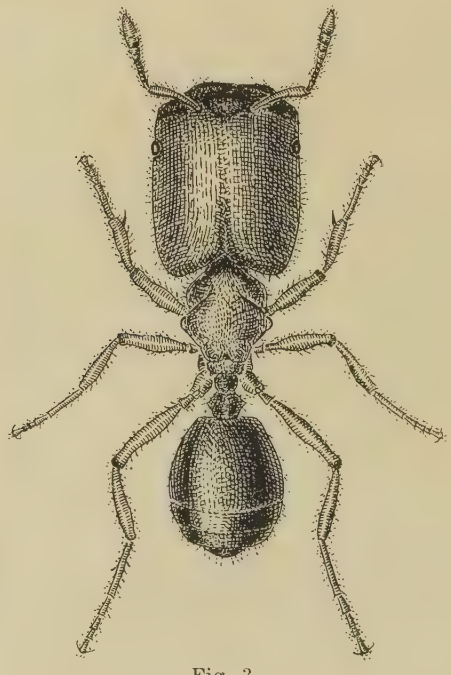

Fig. 3.

Plate 2.

Monomorium (*Monomorium*) *rothsteini* For. var. *leda* For.—Fig. 1. Winged female × 10; fig. 2. Worker × 10; fig. 3. Soldier × 10.

[*Drawings by William Manley.*

Differences in the thoracic colour of workers from separate nests are also apparent, though there are no parallel structural distinctions of any importance. All forms have been identified as *M. rothsteini* var. *leda*.

The species has been collected in the Mareeba and Dimbulah districts and is particularly common on river silts and brown sands. Occasionally nests have been noticed in creek or river beds which are subject to frequent inundation during the summer months. The nest openings are often surrounded by bare patches on which the growth of vegetation is inhibited by the frequent deposition of excavated soil and scattered debris from the nest. One or more runways lead from the nest opening to the main foraging areas. Close to the nest each runway is devoid of vegetation and can be traced for some distance to a point at which the workers scatter in search of suitable provender. Grass seeds are apparently an important element in the dietary, being carried into the nest with the glumes intact. These glumes are removed from the caryopsis in one piece and are subsequently carried from the granaries to dumps one foot or more from the nest opening, whence they are ultimately scattered by rain and wind. Several heaps of refuse from the granaries frequently occur in the vicinity of a single nest.

The many exits from an old-established nest are linked by sub-surface tunnels which are themselves joined to the brood chambers and granaries situated at greater depths. Galleries branch from the main vertical tunnel to a depth of about 18 inches and lead to a series of roomy chambers. Deep vertical tunnels comparable to those in nests of *P. mjobergi* and *P. impressiceps* have not been observed.

During the nuptial flight period, winged forms are escorted from the nest by the workers in the early morning. Several leave each day over a considerable period and, pending emergence, both males and females congregate in the superficial parts of the burrow system. The workers are very active during the nuptial flight and cluster round the nest openings with their mandibles in constant motion. Many grip the appendages of the migrants, apparently forcing them on a path which they show little inclination to follow. Several functional queens may be found in the one nest.

Though most runways converge on a single nest, which is thus the focal point of worker movements, paired nests linked by a prominent path have occasionally been observed. In one instance two nests, complete with brood chambers and granaries, were joined by a runway along which the workers streamed in only the one direction. On dissection of the nests it was found that all the immature forms were in the nest to which the insects were moving and which was situated on the fringe of recently-ploughed land.

As with many other seed-harvesting species, foraging activities during the hotter hours of the day are slight. Normally, ant movements commence sluggishly at dawn and more and more workers pour out from the nests as temperature rises. Most of the workers take refuge within the nest from extreme

heat, but when foraging over considerable distances a few stragglers do not return to the nest, and shelter under any available debris. Activities are resumed in the afternoon when the temperature is falling but cease at nightfall, when all the workers return to the nest.

Some idea of the damage effected by this species can be gathered from estimates of the seed brought to a nest by foraging workers. One-minute counts at various times of the day showed that from 600 to 5,000 seeds passed into one nest opening each hour, the variation being a reflection of harvesting activities at any particular time. Any seeds collected are usually brought direct to the nest from the foraging area. Occasionally, however, workers have been observed accumulating seed in temporary dumps during the morning, the small heaps being removed to the central nest during the afternoon. This habit is apparent only when workers are foraging far from the nest and involves the collection of seed at focal points reasonably close to runways. The phenomenon may partly explain the relative scarcity of workers on the runways during the morning; for, once the ants have entered a foraging area, they may remain to heap the seed at suitable places from which it can later be removed to the nest.

The destructive habits of this species are directly attributable to the extraordinarily large number of ants in a single nest, for these can harvest an enormous number of seeds in a very short time.

Monomorium (Parholcomyrmex) gracillimum Smith.

Though *M. gracillimum* is not a dominant species in tobacco-growing districts, nests of this ant have been found in and near seed-beds, from which the workers have been observed removing seed. It is rather a distinctive species though the worker is only 2·5mm. to 3mm. in length. The anterior segments are fuscous, but parts of the head may be almost black. Parts of the gaster may also be black. The metanotum has a pronounced lateral flange on each side towards the rear edge and some ridging is apparent between the two flanges. The whole of the anterior segments may possess reticulate ornamentation, and the body is more or less hairy. Males have been taken from the nest prior to the nuptial flight; they are 7mm. in length and jet black in colour, except for the distal appendages of the limbs.

The nest has a simple opening which leads directly to a sub-surface chamber and thence to brood chambers at a greater depth. As many as seven queens have been collected in a single nest. During flight periods, alate forms are escorted to the nest opening by the workers. Emergence usually occurs in the early morning and continues for some weeks, the winged insects remaining in the reception chambers just below the surface between successive flights.

Little is known of the economic importance of this species. Workers freely collect tobacco seed both in the laboratory and in the field but the incidence of the nests is so low that the actual losses attributable to the species are not extensive.

Monomorium (Lampromyrmex) ilia For. var. ***lamingtonensis*** For.

The minute species, *M. ilia* var. *lamingtonensis* has been collected in tropical red earths at Atherton and in silt deposits along the banks of creeks in savannah woodlands at Tumoulin on the upper Tableland—*i.e.*, outside the more important tobacco-growing districts. In the latter area, the workers harvested tobacco seed and carried it to nests situated in the beds. The nest openings are small, with a slight symmetrical mound, and a number may occur in the one seed-bed, possibly as independent openings to the one nest.

Workers only have been collected. They are small—1.5mm. to 2mm. in length—and are fulvous in colour. When resting they are difficult to detect, for their outlines are more or less masked by the pale background of the soil. In general appearance, they resemble the workers of *Pheidole variabilis*, but can be distinguished from them by the absence of surface sculpturing and thoracic spines.

Pheidole impressiceps Mayr. (Plate 3.)

Probably the best-known seed-harvesting ant in tobacco-growing districts is *P. impressiceps*; its nests are very common in soils of the river silt type. Only workers are normally seen above ground foraging for seed.

The workers are comparatively small, varying in length from 1·5mm. to 3mm., though individuals from any one nest are almost identical in dimensions. The head, thorax and pedicel are reddish-brown in colour, but the gaster is almost black. In old specimens the head may be darker than the thorax. The

Fig. 1.

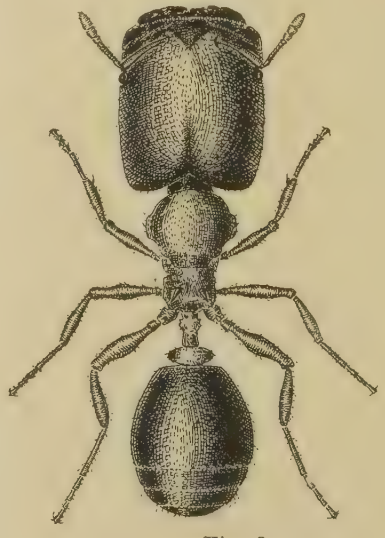

Fig. 2.

Plate 3.

Pheidole impressiceps Mayr.—Fig. 1. Worker × 14; fig. 2. Soldier × 14.

[*Drawings by William Manley.*

soldiers are much larger—4mm. to 4·5mm. in length. In both forms all parts of the body, other than the gaster, may be ornamented with reticulate sculpturing, the intensity of which varies from segment to segment.

The external openings of the nest are of two types, which can be distinguished by the mounds characteristic of each. In one type the nest opening is about 5mm. in diameter and is surrounded by a symmetrical crater-like mound: the nests to which it leads contain workers of relatively small size. The other type of opening is bounded by an asymmetrical crater, grass seed glumes being conspicuously displayed on the tapering margin. The workers inhabiting nests underlying this type of mound are relatively large. In the field the type of worker can always be determined by the conformation of the mound. However, no morphological differences other than size can be detected and both forms are grouped as the one species, *P. impressiceps*.

Each nest is entered through a number of external openings, which may be separated by distances of three or four feet, though frequently they are much closer. Immediately beneath each opening is a reception chamber in which seed may be dumped by foraging workers. While some workers use these chambers, others carry the seed directly to granaries at a greater depth. Nest openings and reception chambers are linked together at a depth of one or two inches by underground tunnels, which in turn connect with vertical passages leading to the nest proper. The approach to the heart of the nest never lies immediately beneath the external openings and cannot be interfered with through accidents which may temporarily close an exit. There may be more than one series of brood chambers and granaries, and each of these series is approached by an independent path from the sub-surface tunnel connecting the exits. Brood chambers and granaries are commonly found in lateral galleries which branch from the main vertical tunnel at depths of from one to three feet. The regal apartments may, however, be situated at much greater depths. In one nest, the underground tunnels, brood chambers and galleries were successively exposed in the soil profile and the approach to the regal chamber traced to a depth of four feet. Even at this depth, the nest had not been completely explored, but the data give some idea of the ramifications in nests of this species. Normally, soldiers are found associated with brood chambers and granaries, their protective and other activities being confined to these essential parts of the nest.

During the spring months it is not uncommon to encounter winged forms in the reception chambers near the surface. They are attended by both soldiers and workers, all forms showing considerable activity during the nuptial flight. Numbers of both males and females leave each day.

The species is essentially granivorous and harvests the seeds of numerous grasses and other herbaceous plants in the vicinity of the nest. The glumes and associated debris are subsequently discharged from the nest and accumulate at the edge of the mound fringing the external opening. The kernel of grass seeds is neatly detached from the glumes by mandibular incisions at its point of attachment, but the several glumes still cohere and can be removed from the nest in one

piece. Grass seed residues are common at nest openings in tobacco seed-beds and indicate that grass seeds had been accumulated in the granaries before the superficial parts of the nest were destroyed during the construction of the beds.

The activity of the workers is apparently influenced by temperature: foraging is confined to the morning and late afternoon during fine weather, the workers showing a rhythmical activity similar to that exhibited by *M. rothsteini* var. *leda*.

Tobacco seed is readily collected if available. Usually one or more nests occur in, or close to, any seed-bed and losses will probably take place if protective measures are not adopted. Frequently mounds at the nest opening are clustered with seedlings which result from the germination of seed dropped by foraging workers or rejected at the nest. Similar groups of seedlings have been located in the reception chambers beneath the nest opening.

Pheidole variabilis Mayr. (Plate 4.)

A common seed-harvesting ant which is widely distributed in North Queensland is *P. variabilis*. It has, therefore, been an important factor in seed-bed losses reported from tobacco-growing districts. The worker is comparatively small, being only 1·5mm to 2mm. in length. The head, thorax and pedicel are heavily chitinized, and the surface is ornamented with a reticulate pattern, the intensity of which is greatest on the prothorax. The gaster is fulvous and

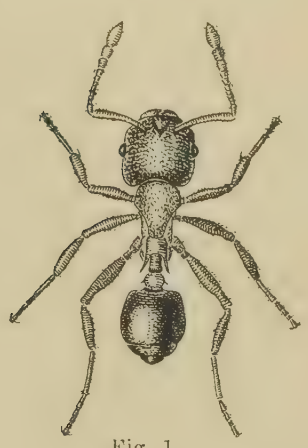

Fig. 1.

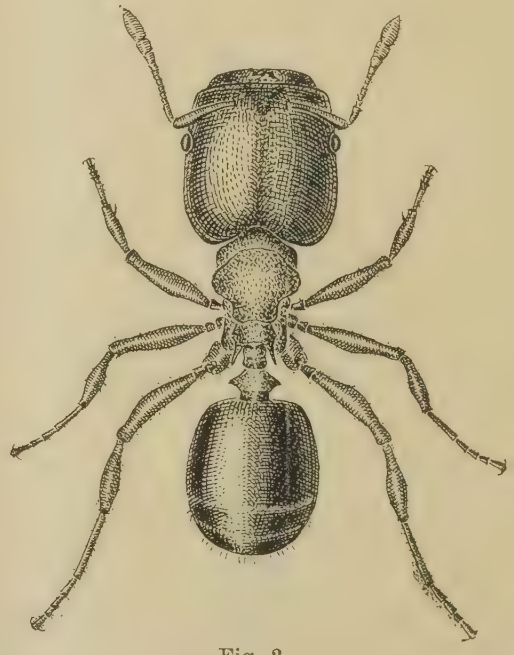

Fig. 2.

Plate 4.

Pheidole variabilis Mayr.—Fig. 1. Worker × 20; fig. 2. Soldier × 20.

[*Drawings by William Manley.*

lacks ornamentation. The metanotum carries a pair of backwardly-projecting spines. The soldier is much larger than the worker, being 3·5 mm. in length. Apart from the typically large, square head it resembles the worker, the thoracic ornamentation being again distinct. Both worker and soldier have sparsely-placed hairs on all parts of the body.

The external opening to the nest is small and is surrounded by a symmetrical mound of fine soil particles removed during construction and maintenance. Groups of quartz grains are occasionally found in some galleries. A number of openings may lead to the same nest and communicate with each other by sub-surface tunnels about two or three inches beneath the surface. The main body of the nest is frequently one or two feet below ground level and may be built round an old root buried in the soil. The vertical approach to the nest communicates with the sub-surface tunnels and not directly with the external opening. At the centre of the nest, brood chambers and granaries are in close association and consist of lateral galleries with one or two square inches of floor space branching from the vertical tunnel. Brood chambers and granaries are often arranged in series at different depths and, being very similar, could serve either purpose equally well. Reception chambers may occur just below the external opening and are frequently used as subsidiary granaries. Seed may be lodged in them during harvesting operations.

Soldiers are numerous in the vicinity of the brood chambers and galleries. Unlike the soldiers of some other seed-harvesting species, they frequently take an active part in aggressive movements outside the nest. In one conflict between *P. variabilis* and *P. impressiceps,* stimulated by attracting workers from nests of both species to some tobacco seed, workers of *P. variabilis* clung to the appendages of the larger *P. impressiceps* while soldiers decapitated first one captive, then another, by mandibular incisions just behind the head.

During the spring and summer months, winged forms which have reached maturity congregate in the superficial parts of the nest. Towards late afternoon the workers and soldiers, sponsoring the migration, escort the winged forms to the open. Flights take place on successive nights for some weeks; the males far outnumber the females.

Nests of *P. variabilis* may contain immense numbers of workers. They are relatively slow-moving insects whose foraging range is limited, and runways can seldom be traced more than one or two yards from the nest opening. The importance of the species is therefore due less to seed-bed invasion from distant nests than to the activity of workers from nests in and near the planted area. The numerical incidence of nests on soils of the river silt type is normally such that few beds escape the attention of foraging workers.

The small size of the workers doubtless has some influence on the choice of seeds suitable for their communal food requirements. Granaries are usually stocked with minute weed seeds drawn from the native flora; the larger grass seeds furnish a relatively small proportion of the provender. The size of the

seeds of the commoner grasses would raise transport problems beyond the ingenuity of the workers, and it is not surprising, therefore, that discarded glumes seldom appear at the mound round the nest opening.

Pheidole anthracina For.

The species, *P. anthracina,* is recorded from the Mareeba district. Its workers are small—1·5mm. in length—and are somewhat dark in colour; in some specimens the head and gaster are almost black. Reticulate sculpturing is present on the head, thorax and pedicel, but the gaster is quite smooth. The metanotum carries a pair of prominent spines. This species is partial to tobacco seed.

Pheidolacanthinus mjobergi For. (Plate 5.)

An ant with rather a curious distribution in the tobacco-growing areas is *P. mjobergi.* Its nests are quite common at Biboohra and Bilwon and serious losses have been attributed to the insect in these localities. Elsewhere in the Mareeba district the species is of little importance to the tobacco-grower, though occasional nests have been located on both brown sands and river silts.

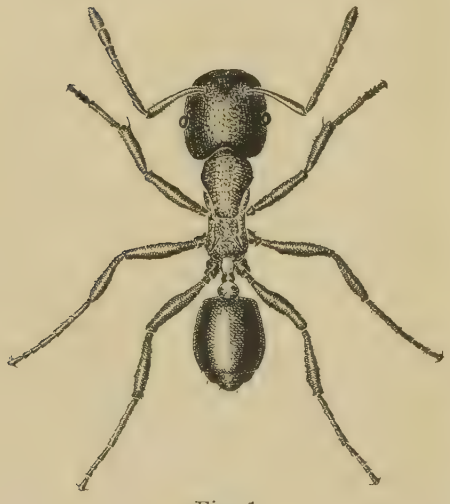

Fig. 1.

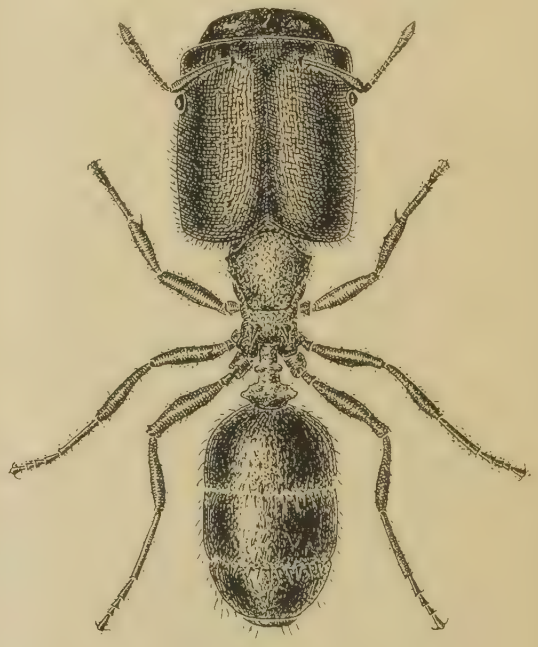

Fig. 2.

Plate 5.

Pheidolacanthinus mjobergi For. Fig. 1. Worker × 14; fig. 2. Soldier × 10.

[*Drawings by William Manley.*

The workers are 3mm. in length and uniformly dark-brown in colour. The head, thorax, and pedicel are heavily chitinized and the surface carries a reticulate sculpturing which is absent from the gaster. On the dorsum of the

head and thorax linear striations run parallel to the length of the body; on the metanotum two lateral ridges terminate in upwardly projecting spines. The body is covered with scattered hairs.

Normally the external openings of the nest are connected by sub-surface tunnels. Beneath each opening is a reception chamber in which garnered seed may be placed. From the sub-surface tunnels vertical paths lead to brood chambers and granaries in the centre of the nest. These may be placed in series along the vertical tunnels at depths of from one foot to three feet. The main vertical tunnel has been traced to a depth of six feet.

Being relatively large, the workers can forage a considerable distance; and, as large numbers are frequently associated with the one nest, seed-beds established nearby are very soon discovered and seed on them harvested. Unlike most harvesting ants found in tobacco seed-beds, the workers of *P. mjobergi* may also remove the cotyledons from the young plant, and thus destroy seed-beds in which the initial germination is satisfactory. Some other species may occasionally detach the cotyledons from seedlings, but only *P. mjobergi* causes serious injury of this nature.

***Meranoplus* sp.**

Though most species of *Meranoplus* are seed-harvesting forms, they are comparatively large insects and normally pay little or no attention to tobacco seed. However, the smallest species occurring in tobacco-growing districts does roam over seed-beds and may take seed which is suitably exposed. It is apparently unnamed.

The worker is about 2mm. long; the head and thorax are shield-shaped, with fringing flanges which stretch beyond the sides of the body; and the dorsal surface is covered with a thick mass of hairs. Unlike the head and thorax, which have a superficial reticulate pattern, the gaster is smooth and is covered with hairs on all sides. The thoracic shield is serrated at the lateral edges. Both head and thorax are almost black in dorsal aspect, while the abdomen is a reddish-yellow which contrasts strongly with the anterior part of the body.

The nests are usually simple and are entered by one or more external openings quite close together which lead to shallow underground chambers. This ant is not an active species and is of secondary importance in the seed-harvesting ant fauna.

Other Seed-harvesting Ants.

A number of species which belong to seed-harvesting genera are, as yet, of no economic importance in the tobacco-growing districts. The commonest of these is *Monomorium (Lampromyrmex) laeve* Mayr. var. *nigrior* For., a small, glossy-black ant. *Tetramorium guineense* Fab., a fuscous ant whose workers are 2mm. to 2·5mm. in length, is occasionally found nesting in seed-beds. *Pheidole longiceps* Mayr., a minute fuscous ant, is recorded from nests in the Mareeba district. Three species in the genus *Meranoplus*—*M. mars* For. s.sp. *ajax* For.,

M. fenestratus Sm. var. *christmasensis* For., and *M. hirsutus* Mayr. var. *minor* For.—are commonly encountered. They are all much larger than the unnamed species discussed earlier, and they forage chiefly among plants which yield comparatively large seed.

THE CONTENTS OF GRANARIES.

In dissecting the nests of seed-harvesting ants established on various soil types, marked differences in the granary contents were apparent. The contents to some extent reflect the variety of the flora in the vicinity of the nest and the species of plants shedding seed for some weeks prior to the examination. Thus, the seed located in any one nest depends on (*a*), the time of the year, because seasonal conditions influence both the setting and shedding of the seed; (*b*), the character of the flora, which will determine the variety of seeds taken into the nest; and (*c*), the ability of the workers to collect the several types of seed available.

Some seeds are shed without any protective covering but others are enclosed in glumes, bracts or comparable structures. All seeds stored for any length of time in the nest lack protective appendages and are kept in heaps on the granary floors. Usually seeds from different species of host plants are stored in separate granaries or in separate heaps in the same granary. The manner in which the insect deposits glumes and other debris outside the nest is sometimes characteristic of the species. Thus of three important species which harvest grass seeds, *M. rothsteini* var. *leda* deposits the debris in small heaps one foot or more from the nest opening, *P. mjobergi* distributes the refuse evenly round the exit, while *P. impressiceps* places it at one side of an asymmetrical mound.

Foraging ants frequently collect seed from a single plant species growing in the vicinity of the nest. If a worker finds a readily accessible seed supply the news rapidly spreads through the colony and, in a short time, foraging activities which were previously scattered are concentrated at the one spot. Such discoveries usually comprise heavy seed deposits from plants of the same species and collaborating workers fill one granary before proceeding to the next. This habit is illustrated by the behaviour of the ants when tobacco seed was laid out in heaps over the foraging area, for the workers soon found it and avidly collected the seed to the exclusion of less accessible material. Subsequent dissection of the nests showed that the granaries were each filled with several heaps in which tobacco seed was by far the most important constituent. Seed types which are numerically of minor importance in any particular granary are doubtless brought to the nest by workers foraging apart from the majority of the nest population.

Granaries of *M. rothsteini* var. *leda*, *P. impressiceps* and *P. mjobergi* were repeatedly examined and a variety of seeds collected from each. The correlation of these seeds with the parent plant is difficult, for the seeds of the

native flora are not well known. The typical flora was sampled, however, during the summer and winter months and any seeds obtained systematically compared with those recovered from ant nests.

Two grasses, *Brachiaria piligera* and *Eleusine indica* together with the two weeds, *Portulaca oleracea* and *Desmodium Muelleri,* have been taken from the nests of the three seed-harvesting species, *M. rothsteini* var. *leda, P. impressiceps* and *P. mjobergi.* Six other plants are known to furnish seeds suited to the needs of *M. rothsteini* var. *leda* and *P. impressiceps,* viz., *Setaria Brownii, Chloris virgata, Eragrostis elongata, Crotalaria trifoliastrum, Cassia mimosoides* and *Ageratum conyzoides.* Other seeds taken from the nests of one or other of these two ants belong to the following plants:—*Digitaria gibbosa, Vigna luteola, Setaria glauca, Rottboellia formosa, Spermacoce sp., Ipomaea eriocarpa, Pimelea cornucopiae* and *Phyllanthus minutiflorus.*

These seeds show a considerable variation in size and illustrate the range of seed types which can be collected by some of the more important seed-harvesting ants. Thus *M. rothsteini* var. *leda* may collect both the minute seed (·7mm. in length) of *Eragrostis diandra,* and the seeds of *Vigna luteola,* which are 3mm. long and nearly 2mm. in diameter. Similar contrasts are apparent in other species, but it seems quite clear that while the minute seeds may be collected by all seed-harvesting ants some large seeds are beyond the power of small ants to handle. Size is not, however, the only determining factor, because the shape of a seed may largely determine its suitability or otherwise for any particular species of ant. Thus a moderate-sized, round seed may be more difficult to carry to the nest than a larger, angular one.

The herbaceous plants collected in the tobacco-growing districts are listed in Appendix 1, together with records of the occurrence of their seeds in the granaries of three important ant species.

THE DISTRIBUTION OF ANT SPECIES.

Ant nests in tobacco-growing districts were sampled to determine the distribution and importance of individual species, and it soon became apparent that the composition of the ant population varied a great deal.

For purposes of comparison, the ant fauna was examined in the Dimbulah district in three selected types of soil—white sands, brown sands, and river silts. In the white sands, the dominant species were *Iridomyrmex detectus* s.sp. *sanguinea, I. rufoniger* s.sp. *pallidus* and *Paratrechina* (*Nylanderia*) *obscura.* Granivorous species were absent. The dominant species are all comparatively large insects, capable of foraging a considerable distance from the nest. In the brown sands, which are particularly suitable for tobacco-growing, these large species were present, together with a number of seed-harvesting ants. The latter included species in the genus *Meranoplus,* but only occasional formicaries of small seed-harvesting ants of the genera *Pheidole* and *Monomorium* had been established. Several species in the genus *Crematogaster* were also common.

In the river silts, seed-harvesting species in the genera *Pheidole, Monomorium* and *Meranoplus* comprised the greater part of the ant fauna, *P. impressiceps* and *P. variabilis* being represented by innumerable nests.

This distribution of species can scarcely be a matter of chance and some possible explanations warrant discussion. Most formicaries are built in the ground and may penetrate to considerable depths. During nest construction and maintenance, the workers carry small particles of soil from below ground to mounds at the nest opening. These workers vary in size from species to species and the minute workers of *P. variabilis,* for example, cannot carry soil particles which are within the compass of larger forms, such as *I. rufoniger.* It is reasonable to suppose, therefore, that the smaller species will be unable to establish nests in soils containing a large proportion of coarse soil particles. The nesting habits of the larger species are not limited in this way and soil texture would have less influence on their distribution.

When dissecting nests and underground tunnels connecting adjacent nests, differences in the texture of the soil were very apparent. The ramifications of formicaries in river silts were traced with comparative ease. In other soils, the collapse of a profile exposed during dissection frequently obscured the tunnel path and prevented the satisfactory study of the nest, though the main thoroughfares could often be rediscovered by noting the point at which the workers cleared a path for themselves. The dissection of nests in the white sands was particularly difficult.

Such variations in the stability of a soil profile suggest that formicaries constructed in a river silt are more durable than those in the other types of soil. As soil texture must largely determine nest stability the binding properties of the soil may be of importance. These properties will vary with the clay content, the amount of humus, and the proportion of fine soil particles. In tobacco-growing soils the clay content is very low and may be disregarded in this connexion. Humus may influence the water-holding capacity of river silts, but in the other soil types there is little humus present. The proportions of fine and coarse particles do, however, vary a great deal in the three soil types and may determine the suitability or otherwise of any soil for the needs of individual ant species.

Samples of the three soil types gave the following mechanical analyses:—

Soil Fraction.	White Sand.	Brown Sand.	River Silt.
	%	%	%
Coarse fragments (2·0—·2 mm.)	85·1	75·8	33·9
Fine sand (·2—·04 mm)	10·6	14·3	41·2
Finer particles (·04—·002 mm.)	2·63	6·64	20·0
Clay (below ·002 mm.)	1·07	1·56	0·8
Organic matter and combined water	0·9	1·1	2·3

The river silt has a much greater proportion of fine soil particles than either of the other soil types, and the brown sand holds an intermediate position between the river silt and the white sand. The ant distribution can thus be correlated with the mechanical texture of the soil, which has an important influence on nest stability and the ability of the workers to carry out tunnel excavation. On this view it may be presumed that, while all soils permit the initiation of formicaries, the successful exploitation of the nest site may be controlled by the mechanical texture of the soil. Ants with large workers may thus establish nests in coarse soils quite unsuitable for the smaller seed-harvesting species whose workers would be unable to handle large soil particles. The latter types would thus tend to congregate in river silts where burrow excavation is a relatively simple matter and nest stability better assured.

The species distribution problem can be approached from another angle. Large ants can find an abundance of food, no matter where the nest is situated, for they are able to forage over considerable distances. Granivorous species, many of which forage only in the immediate vicinity of the nest, depend entirely on seed shed by the surrounding flora. Should these seeds be limited in quantity or unsuited to the needs of a particular species, the restricted food supply would be an effective check on the increase and spread of the insect. It is thus quite conceivable that limited food supplies may keep the seed-harvesting ant fauna at a numerically low level even when the soil type is suitable for nest construction.

Marked differences in the vegetation growing on the three types of soil under discussion are not uncommon, river silts carrying a particularly rich flora comprising an abundance of species. Hence, even though many of the seed-harvesting ants may be able to establish nests in the brown sands as well as in the river silts, the ant population in the latter would be stabilized at a much higher level, for the abundance of plants producing small seeds would maintain a greater number of formicaries.

It seems, therefore, that while the texture of a soil may determine its suitability for nest establishment by the seed-harvesting species, the density of the insect population will be determined by the vegetative cover. Suitable soils with a relatively luxuriant flora would thus carry a greater ant population than similar soils with a stunted and sparsely distributed flora.

THE CONTROL OF ANTS IN TOBACCO SEED-BEDS.

When seed-harvesting ants first interfered with routine seed-bed practices, numerous insecticides of possible value were applied by growers in and near the beds with the object of alleviating the trouble. Several fluid baits, mostly of the syrup type with an added arsenical poison, were used but gave inconsistent results. As a number of species, each with its own specific reactions to any single bait, were usually implicated in the losses, the merits of baiting methods

of control could scarcely be accurately assessed in the field and no fluid bait suitable for general application has been discovered. Contact sprays applied to the beds after sowing the seed also gave negligible results.

These various attempts of growers to combat seed-harvesting ants were, however, useful in a preliminary survey of the position, for they narrowed down the field of investigations. Seed-bed management, quite apart from controlling pests and diseases, is an intricate matter and it was therefore necessary to elaborate modifications in seed-bed technique which could be conveniently adopted by the growers on the assumption that ants are always a potential danger.

Selection of Seed-bed Sites.

When a creek or river runs through a property, seed-beds are usually established on soils of the river silt type situated above flood level. These soils are more fertile and better suited for seedling growth than any of the others available; but, as they are normally thickly populated with ant nests, losses through seed-bed disturbances or seed removal are very common. These losses cannot altogether be eliminated by the careful selection of seed-bed sites, but some important species can be excluded, if a preliminary survey of the ant fauna is carried out, for seed-beds can then be established at a safe distance from the more obvious formicaries.

For example, the funnel ant, *A. longiceps,* is a common species whose formicaries may cover a considerable area. The workers of this species are well known and nests can readily be detected in virgin ground; hence when seed-bed sites are being chosen, areas frequented by the pest can usually be avoided. If seed-beds, through lack of better areas, must be prepared on soils in which the funnel ant is active, a determined effort should be made to destroy the nests by fumigation with carbon bi-sulphide. The method has been described (Summerville, 1929) in a paper dealing with the control of the mound ant. Such drastic treatment should not normally be necessary, for suitable areas free from the nests of this ant are generally available.

Two of the larger seed-harvesting ants, *M. rothsteini* var. *leda* and *P. mjobergi,* can also be avoided in the same way. Unlike the smaller seed-harvesting species, their nests are relatively far apart in all soils. The workers do, of course, forage over considerable distances, but seed-beds situated more than two chains from the nest lie outside the normal range of their activities. Nests of *M. rothsteini* var. *leda* are fairly common and special attention should be paid to the incidence of this pest in any preliminary survey.

Modification of Seed-bed Management.

The careful selection of seed-bed sites remote from the distinctive nests of *A. longiceps, M. rothsteini* var. *leda* and *P. mjobergi* is only a partial solution of the problem. Quite a number of important species, such as *P. impressiceps* and *P. variabilis,* nest in profusion in river silt soils and possibly no site could be chosen which would not cover some nests or lie within the foraging range of

their workers. Special measures must therefore be elaborated for these species, which, on account of their wide distribution, probably cause greater losses than the larger ants already discussed.

In normal seed-bed practices as observed in North Queensland for some years after establishment of the tobacco-growing industry the soil was cultivated, burned over, manured and then worked into a fine tilth preparatory to the sowing of the seed. Just prior to sowing, the surface of the bed was compressed by means of a flat board and the seed, after dilution with a given quantity of wood ashes, was broadcast over the surface. The seed-bed was then watered at frequent intervals and the surface kept moist, at least until germination was completed. In the meantime, the beds were sheltered from the sun by storm covers. Seed sown on such compacted beds readily attracted the attention of seed-harvesting ants. When the attacks were heavy, only seed buried beneath the surface of the ground escaped the attention of the ants and any seedlings appearing in the seed-bed could invariably be traced to such seed.

The obvious inference was that a protective cover of soil applied to the beds after sowing the seed would, to some extent, overcome the difficulty by concealing seed from the ants. In the experimental work, sand was substituted for soil to minimize any risk of introducing disease organisms or weed seeds to seed-beds already more or less completely sterilized by burning. An abundance of clean sand is available in the rivers and creeks which cross and recross most of the tobacco-growing districts of North Queensland.

In the preliminary experiments, two seed-beds on each of four farms situated at various centres were top-dressed to a depth of one-eighth inch with sand taken direct from a river bed, the scheduled quantity required for the area being estimated previously and broadcast by hand after the seed had been sown. On those farms where the ants were observed to be active, a very irregular stand of seedlings was obtained on untreated beds, while on sanded beds germination and subsequent plant establishment were satisfactory. Variations in the depth of the cover are unavoidable when the sand is broadcast by hand, but these minor differences in no way affected the value of the treatment. Curiously enough, on the seventh day after treatment, seedlings appeared uniformly above ground in the covered beds, the period being slightly less than the usual eight day pre-germination period.

These preliminary trials indicated the usefulness of the sand cover technique, but some additional points still required investigation. The one-eighth inch cover already used was purely an arbitrary selection and the efficiency of greater and lesser depths needed checking. Again, sand taken from a river bed includes particles of all dimensions, which may individually have quite different properties when used in a sand cover.

In a further series of experiments, the sand was separated into two grades and each was used independently in cover thicknesses ranging from one-twelfth to one-half inch. When the covers did not exceed one-quarter inch,

seedlings appeared above ground within the scheduled eight day period and gave an even stand of plants. Covers of greater depths were less satisfactory, the seed germinating slowly and irregularly. The failure of beds with such excessive covers was due, not to the activity of seed-harvesting ants, but to the suppression of plant growth by the heavy top-dressing of sand.

The relative merits of two grades of sand were studied by comparing covers of similar depths on adjacent seed-beds. The river sand was first sieved into two grades, fine sand being that portion containing particles 1·5 mm. or less in diameter, and coarse sand, that portion with particles not less than 1.5 mm. and not more than 2 mm. in diameter. Judged by the appearance of the seedlings on the several treated beds, the texture of the sand was of little importance in covers less than one-quarter inch in depth. Thicker covers of either fine or coarse sand hindered germination. Covers of fine sand one-half inch in depth almost inhibited seedling development, while a similar covering of coarse sand permitted the growth of only an irregular and scanty crop of plants.

It is thus clear that sand covers adequately protect tobacco seed from harvesting ants. These insects rarely penetrate into the soil in their search for food but confine their attention to seed exposed on the surface. For ordinary purposes, the coarse sand retained by a 16-mesh sieve can be applied to the beds, provided the cover does not exceed one-quarter inch. With overhead watering, fine sand tends to pack and may inhibit the growth of the plants. Normally there is no need to use covers greater than one-eighth inch in depth. Thus, in practice, the sand is taken from the river bed, sieved, and that portion retained by a 16-mesh sieve broadcast by hand. Accepting one-eighth inch top-dressings as a convenient standard, 1½ kerosene tins (a kerosene tin has a capacity of four imperial gallons) of sand are required for each 100 square feet of seed-bed.

When the sand covering technique was first proposed, some doubts were expressed as to its cultural applicability, for it appeared to clash with the normal practice of sowing the seed on the surface of compacted soil. Both farmers' experience and the experimental work already outlined show that sand covers used in the prescribed manner have no detrimental effect on seedling development and allow sufficient latitude for ordinary farm practice. Indeed, sand covers have cultural advantages of some moment. As a mulch, they tend to conserve moisture in the soil and to minimize any disturbance to the surface of the seed-beds by storms or indiscriminate watering shortly after germination. Rapid and even germination are also characteristics of seed-beds which have been top-dressed with sand. It appears, therefore, that the practice of sowing seed on the surface of compacted soil had evolved from the need for uniform germination rather than from the inability of seedlings to emerge through a covering layer of soil.

The sand cover method of protecting seed-beds from the ravages of seed-harvesting ants is now in general use in North Queensland, the seed being sown on the compacted soil before the cover is applied.

In some instances, growers, finding sand not readily procurable, have used ordinary soil in its stead, but this alternative is undesirable. The risk of introducing weed seeds and disease organisms to sterilized seed-beds is much greater when soil is used in place of sand and some soils have the further disadvantage that caking of the surface may occur when they are used for covering tobacco seeds. If soil covers must be used, the required quantity of soil should be pre-treated by burning before application to the beds. Even with sand covers, the indiscriminate collection of sand may introduce weed seeds, in particular those of couch grass, *Cynodon dactylon*, and crow's foot, *Eleusine indica*, to the seed-beds. Well washed sand from the submerged or frequently inundated parts of the creek or river bed is thus best suited for cover purposes.

The Use of Dry Baits.

Although the collection and removal of tobacco seeds from the seed-beds can be prevented by adopting the measures already outlined, *P. mjobergi* and other less important species which harvest cotyledons remain a potential danger. Normally the foraging areas associated with nests of *P. mjobergi* can be avoided when choosing seed-bed sites, but control measures may be necessary should the beds be established before the presence of the pest is thoroughly appreciated. On unsanded beds the workers may collect the cotyledons as soon as germination takes place. When sand covers are in use, however, some time may elapse after germination before the foraging workers locate the seedlings. This interval may be sufficient to minimize the losses in dangerously situated beds but such indirect protection is not always adequate. Supplementary control measures for cotyledon-harvesting species may therefore be necessary.

Harvesting ants gather any conveniently sized food particles occurring within their foraging range and this habit suggested the recommendation of a dry, poisoned bait for the control of the seed-harvesting Nyerere ant in tobacco seed-beds in Nyasaland (Smee, 1929). This bait is composed of finely-ground maize cobs to which Paris green has been added and is described as a satisfactory control measure when the area attacked is extensive. An attempt was made to elaborate a somewhat similar bait for the control of ant species which harvest tobacco seedling cotyledons in North Queensland, but a finely-ground maize meal was substituted for the ground maize cobs as a carrier for the poison.

The attractiveness of the bait was tested observationally in the field. Both *P. mjobergi* and other species harvested a wide range of maize meal-Paris green mixtures from the 10:1 strength to the undiluted meal. When tobacco seed was strewn among baits placed in the vicinity of the nest, both poisoned and unpoisoned meals were collected in preference to the seed, although the latter was ultimately taken into the nest. This preference may be due to the ease with which angular meal particles can be collected by the workers.

Occasionally some of the bait particles were rejected from the nest, although the quantity discarded was always small compared with the total amount harvested. Subsequent dissection of the nests revealed granaries packed

with either poisoned or unpoisoned meal. Rapid destruction of the nest did not occur and would, in fact, only be expected if the food reserves were depleted and the bait was consumed within a short time of its being received into the nest.

Preliminary trials indicated that a dry bait composed of maize meal and Paris green in the proportions 50:1 gave excellent protection to seed-beds, the conclusion being assessed on the seedling survival in susceptible seed-beds. At that time, information concerning the nesting and harvesting habits of the several ant species was limited and maize meal-Paris green baits compounded to the 50:1 formula were tentatively considered suitable for the control of *P. mjobergi*. Shortly after the preliminary trials had been completed, a severe attack by this species on seed-beds at Bilwon took place. The grower attempted to counter the invasion by sowing at four times the scheduled rate, but only a few seedlings appeared above the ground and many of these were destroyed within three weeks of germination. Both newly-sown and recently-germinated seed-beds were subsequently treated with a 50:1 maize meal-Paris green dry bait broadcast at the rate of 12 oz. per 100 square feet of bed. In this way the attention of the ants was effectively diverted from both tobacco seed and seedlings and, by the systematic use of the bait, the farmer was able to grow an abundance of plants both for his own use and for sale.

As *P. mjobergi* and other species addicted to harvesting cotyledons are irregularly distributed, losses comparable to those just cited have not since been recorded. The workers of this species readily harvest unpoisoned maize meal in preference to both tobacco seed and the cotyledons. Hence, as the diversion of the ants from the plants, rather than the destruction of the nest itself, is the primary aim of control measures, there seems no essential reason for adding Paris green to the maize meal. For ordinary purposes, broadcast applications of maize meal in and around the beds, together with a further distribution of the bait in the vicinity of the ant nests if these can be located, should meet growers' requirements. The rate of application should be retained at the level found effective for the poisoned bait, viz., 12 oz. per 100 square feet of seed-bed. Protection may be necessary for about three weeks after germination; by that time the plants are large enough to escape attack. In acute cases, bait applications may be necessary every three or four days but, ordinarily, one, or at most two, treatments will be adequate.

ACKNOWLEDGEMENTS.

The authors are indebted to Mr. J. Clarke, of the National Museum, Melbourne, for examining collections of North Queensland ants and to several fellow officers of the Queensland Department of Agriculture and Stock for assistance in the field and in the preparation of this paper.

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APPENDIX 1.

Herbaceous Plants collected in Tobacco-Growing Districts.

	Seeds found in granaries of		
	M. rothsteini	*P. impressiceps* var. *leda*	*P. mjobergi*
BORAGINACEAE—			
Heliotropium tenuifolium R.Br.			
COMPOSITAE—			
Ageratum conyzoides L.	+	+	
CONVOLVULACEAE—			
Evolvus alsinoides L.			
Ipomaea eriocarpa R.Br.	+		
CYPERACEAE—			
Cyperus sp.			
Fimbristylis sp.			
EUPHORBIACEAE—			
Euphorbia pilulifera L.			
Phyllanthus minutiflorus F. Muell. ..		+	
GRAMINEAE—			
Aristida sp.			
Brachiaria foliosa (R.Br.) Hughes			
Brachiaria piligera Hughes	+	+	+
Chloris pumilio R.Br.			
Chloris virgata Sw.	+	+	
Dactyloctenium aegyptium (L.) Richt.			
Digitaria adscendens (H.B.K.) Henr.			
Digitaria gibbosa (R.Br.) Hughes ..		+	
Echinochloa colona (L.) Link			
Ectrosia leporina R.Br.			
Eleusine indica (L.) Gaertn.	+	+	+
Eragrostis australiensis Domin			
Eragrostis cilianensis (All.) Link			
Eragrostis elongata (Willd.) Jacq. ..	+	+	
Eragrostis japonica (Thunb.) Trin.			
Eragrostis sp.			
Panicum effusum R.Br.			
Panicum maximum Jacq.			
Perotis rara R.Br.			
Rottboellia formosa R.Br.		+	

APPENDIX 1—continued.

Herbaceous Plants collected in Tobacco-Growing Districts—continued.

	Seeds found in granaries of		
	M. rothsteini	*P. impressiceps*	*P. mjobergi* var. *leda*
GRAMINEAE—continued.			
Setaria Brownii Herrm.	+	+	
Setaria glauca (L.) Beauv.		+	
Sporobolus capensis Kunth.			
Thaumastochloa pubescens (Domin) C. E. Hubbard			
LEGUMINOSEAE—			
Aeschynomene americana L.			
Atylosia scarabaeoides L.			
Cassia absus L.			
Cassia concinna Benth.			
Cassia mimosoides L.	+	+	
Crotalaria crispata			
Crotalaria linifolia L.f.			
Crotalaria trifoliastrum Willd.	+	+	
Desmodium biarticulatum (DC.) F. Muell.			
Desmodium Muelleri Benth.	+	+	+
Indigofera enneaphylla L.			
Indigofera viscosa Lam.			
Rhynchosia minima DC.			
Vigna lanceolata Benth.			
Vigna luteola (Jacq.) Benth.	+		
Zornia diphylla Pers.			
LOGANIACEAE—			
Mitrasacme iongiflora F. Muell. ex Benth.			
MALVACEAE—			
Sida rhombifolia L.			
PORTULACACEAE—			
Portulaca oleracea L.	+	+	+
PRIMULACEAE—			
Anagallis pumila Sw.			
RUBIACEAE—			
Richardsonia brasiliensis Hayne			
Spermacoce sp.		+	
SCROPHULARIACEAE—			
Herpestis floribunda R.Br.			
STERCULIACEAE—			
Melhania oblongifolia F. Muell.			
THYMELAEACEAE—			
Pimelea cornucopiae Vahl.		+	
TILIACEAE—			
Corchorus acutangulus Lam.			

APPENDIX 2.

Named Ants from Mareeba and Dimbulah.

Sub-Family *PONERINAE*—

Odontomachus ruficeps Sm.

Ponera convexiuscula For.

Sub-Family *MYRMICINAE*—

Aphaenogaster (*Nystalomyrma*) *longiceps* For.

Crematogaster (*Acrocoelia*) *fusca* Mayr.

Crematogaster pallipes Mayr.

Crematogaster pythia For.

Meranoplus fenestratus Sm. var. *christmasensis* For.

Meranoplus hirsutus Mayr. var. *minor* For.

Meranoplus mars For.

Meranoplus mars For. s.sp. *ajax* For.

Monomorium (*Parholcomyrmex*) *gracillimum* Sm.

Monomorium (*Lampromyrmex*) *ilia* For. var. *lamingtonensis* For.

Monomorium (*Lampromyrmex*) *laeve* Mayr.

Monomorium (*Lampromyrmex*) *laeve* Mayr. var. *nigrior* For.

Monomorium (*Monomorium*) *rothsteini* For. var. *leda* For.

Pheidolacanthinus mjobergi For.

Pheidole anthracina For.

Pheidole athertonensis For.

Pheidole impressiceps Mayr.

Pheidole longiceps Mayr.

Pheidole proxima Mayr.

Pheidole variabilis Mayr.

Tetramorium guineense Fab.

Sub-Family *DOLICHODERINAE*—

Iridomyrmex detectus Sm. s.sp. *sanguinea* For.

Iridomyrmex gracilis Lowne.

Iridomyrmex punctatissimus Emery.

Iridomyrmex rufoniger Lowne.

Iridomyrmex rufoniger Lowne s.sp. *pallidus* For.

Iridomyrmex stewarti For.

Tapinoma minutum Mayr. var. *integrum* For.

Sub-Family *FORMICINAE*—

Camponotus (*Tanaemyrmex*) *novaehollandiae* Mayr.

Melophorus formicoides For.

Opisthopsis haddoni Emery.

Opisthopsis pictus Emery var. *lepidus* Wheeler.

Paratrechina (*Nylanderia*) *obscura* Mayr.

Polyrachis (*Chariomyrma*) *aurea* Mayr.

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